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IDENTIFICATION OF SOUND SOURCE AZIMUTH  
WITH ACTIVE AND PASSIVE HEARING PROTECTORS

INTERIM REPORT

By

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A stimulus identification procedure was used to investigate the effects of active and passive circumaural hearing protectors on static auditory localization ability. Signals were long duration broad band noise bursts presented randomly from 36 equally spaced transducers arranged in a circle. Results indicate that, in some subjects, the passive devices caused an approximate 180° shift in perceived azimuth without reducing the available range of locations. The active devices effectively eliminated localization ability by reducing the number of perceptual loci to one or two. Loss of localization ability is attributed to electroacoustic deficiencies of the active circuits. *Keywords:*

*hearing protection devices; Army artillery observer; noise exposure control vehicle observer*

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## INTRODUCTION

The research reported here was carried out as part of a contract with the U.S. Army Medical Research and Development Command to develop a system for rapid assessment of human auditory localization ability as affected by various hearing and ballistic protection devices. The specific impetus for this research originated with a recognition that degraded ability to localize sounds in space is likely to reduce personnel effectiveness in noisy environments generally and in combat conditions specifically. Two hearing protection systems were selected for this first study. One, designated DH-178, is a prototype ballistic helmet combined with circumaural hearing protection intended for use by U.S. Army artillery crewmen. This system is comprised of an abbreviated fiberglass shell suspended on a foam rubber and nylon web liner which also holds large volume rigid plastic circumaural hearing protectors. These earcups each contain an independent miniature microphone, amplifier, and earphone providing a "tail-through" channel intended to allow speech signals to bypass the attenuation of the earcups in low noise levels. The amplifiers are actively amplitude limited by compression circuits.

The other system, designated DH-140, is similar and is presently used by the U.S. Marine Corps in several applications, primarily by combat vehicle crewmen. This system differs slightly from the DH-178 in external dimensions and surface texture. Suspension of the ballistic shell is by nylon and leather webbing. The active circuits of the hearing protectors both receive input from a single miniature microphone mounted on the left earcup. For the purposes of this study the essential difference between the two systems is that the DH-178 provides the wearer with dichotic or independent input to the two ears; the DH-140 provides a diotic or completely correlated input to both ears.

Auditory localization is a complex perceptual process based on information derived from several sources. These have been reviewed extensively (Searle et al, 1976; Searle, 1982) and will be merely mentioned here. The most commonly known cues are interaural amplitude difference (head shadow), which operates in the frequency range from 1 kHz to 12 kHz, and interaural time delay, in the range of 20 Hz to 12 kHz. Monaural head shadow is useful from 1 kHz to 12 kHz (Mills, 1972). Monaural pinna amplitude response operates as a cue from 4 kHz to 12 kHz (Batteau, 1967; Butler, 1969). Interaural pinna amplitude response also operates from 4 kHz to 12 kHz (Shaw, 1974; Searle et al, 1975); and finally amplitude response from shoulder bounce is a cue from 2 kHz to 3 kHz (Gardner 1973).

The investigation of human auditory localization has typically proceeded through two categories of methods using two types of apparatus. In the identification methods the apparent locus of a sound has typically been registered by pointing, by spatially approximating with another sound source, or by

written responding. In the discrimination (sometimes called "minimum audible angle") methods spatial resolution has been measured through discrete responding in a modified constant stimulus paradigm similar to the two-alternative approach used in studies of the theory of signal detection. The apparatus has typically included either a single sound source on a rotatable boom or multiple transducers set equidistant from the observer in a single plane. The most common planes of observation have been the horizontal plane containing the interaural axis (azimuth) and the midsagittal vertical plane (elevation).

These planes of observation have often been restricted to an arc of  $180^\circ$  or less and some minimum angular resolution ranging from  $8^\circ$  to  $30^\circ$ . Systematic errors of localization in which the apparent sound source lies in a quadrant of the plane of observation other than that of the physical source have often been referred to as reversals or confusions. These terms are frequently not well distinguished and their definition often depends on the apparatus used. In this report, the term reversal will be used to mean a consistent disparity between a physical source and its apparent locus which crosses a quadrant boundary. The term confusion will be used to mean an ambivalence in assigning any two apparent loci to one physical source.

In this study multiple transducers were fixed in the azimuthal plane and observers' responses were limited to that plane. Figure 1 is a schematic of the plane of observation with labels for rotational direction and quadrants.

## METHOD

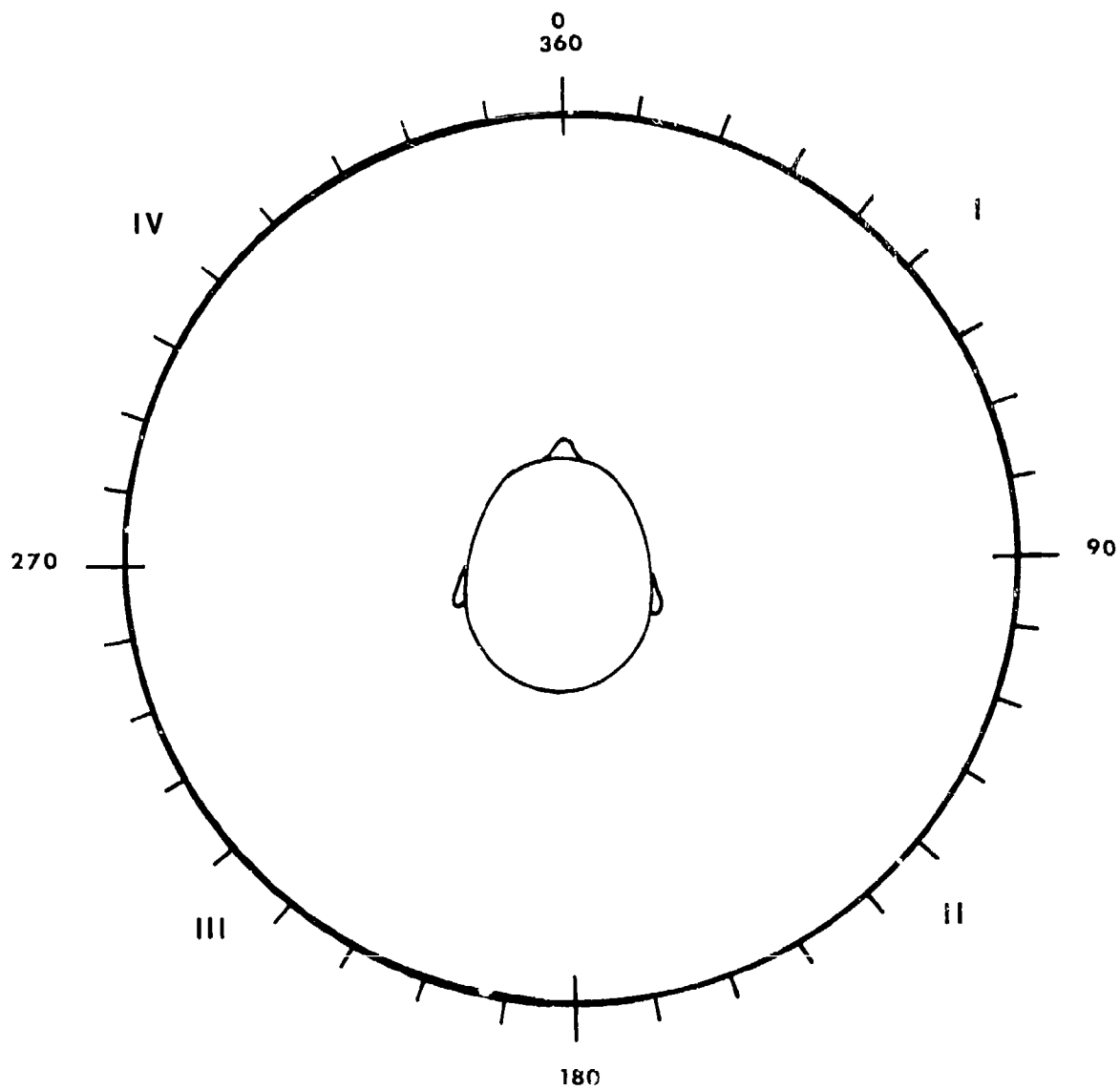
### SUBJECTS

Six paid volunteers ranging in age from 22 to 31 years served as observers. Three of the subjects were male and three were female. All six subjects had pure tone hearing thresholds within normal limits (ANSI, 1969) at audiometric frequencies and also exhibited hearing thresholds at no greater than 20 dB (re: 20  $\mu$ Pa) at 10 kHz. Subjects had no known auditory or vestibular pathologies. Three of the subjects had normal far-field visual acuity and three wore corrective lenses. One of the subjects had extensive experience as a psychophysical observer and one had limited experience.

### APPARATUS

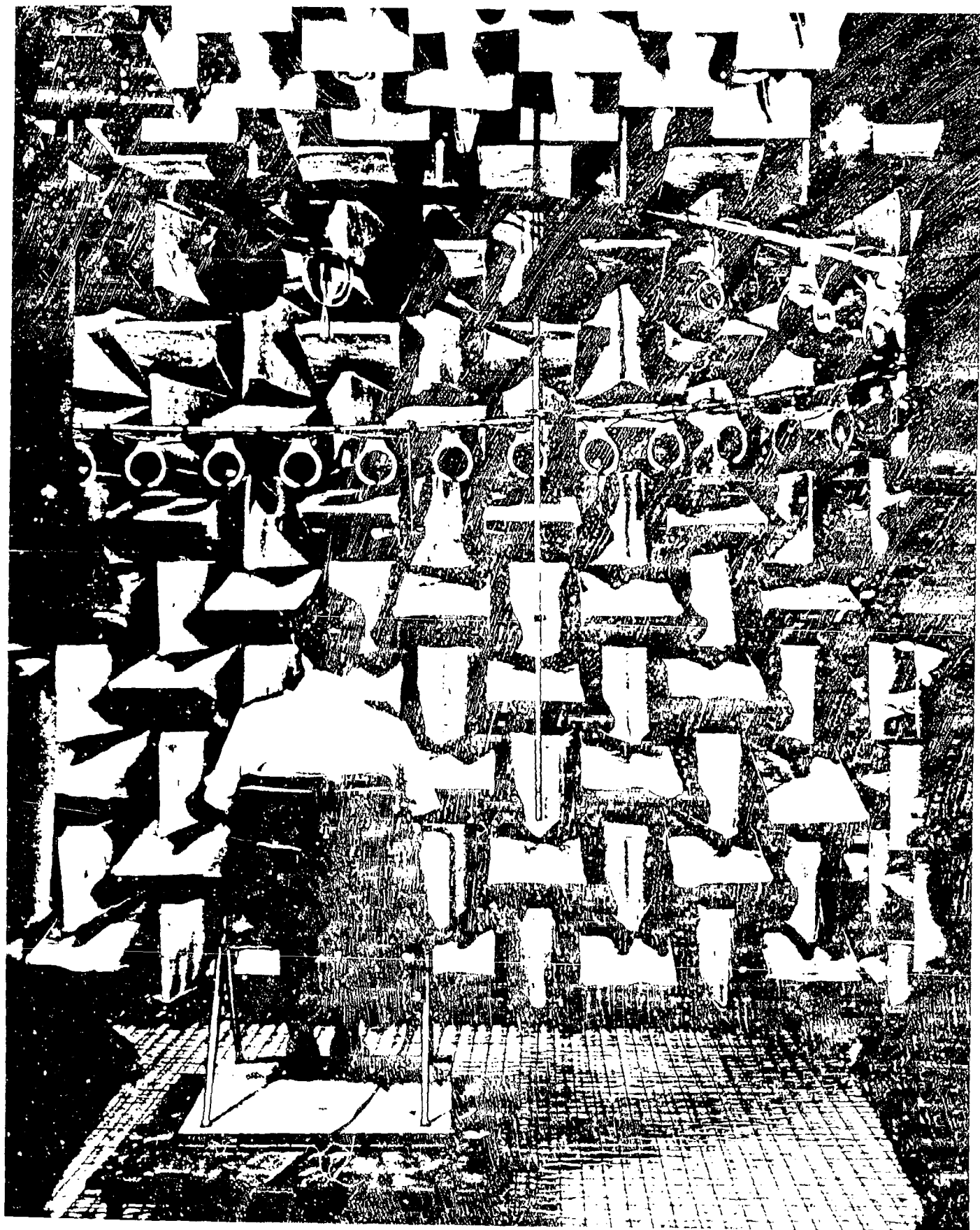
Observations were made in an Industrial Acoustics Company anechoic chamber which measured 10 by 10 by 10 ft inside from wedge tip to wedge tip. Acoustic signals were produced by 36 Oaktron Industries 5 in dynamic speakers mounted at  $10^\circ$  intervals on a 9 ft diameter ring constructed of 1 in o.d. steel pipe filled with glass wool. The ring was suspended 48 in above the cable floor of the anechoic chamber. Figure 2 is a view of the interior of the chamber. The ring of speakers is raised above the normal position in this photograph.





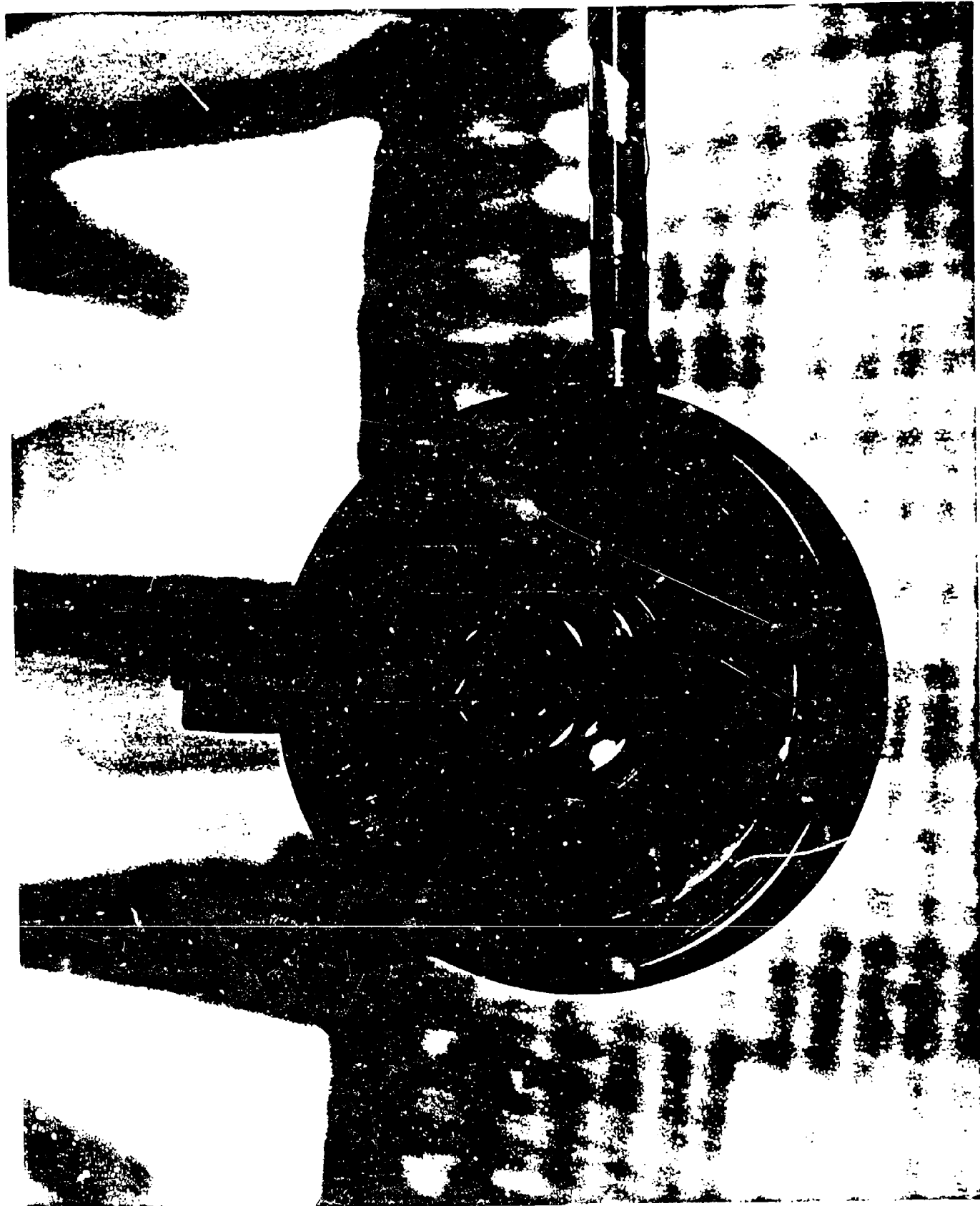
A response manipulandum was constructed using a 6 in diameter circular plastic case supporting a 2 in diameter knob which controlled the position of a  $360^{\circ}$  potentiometer. This provided a continuously adjustable voltage analog (0 through 10 VDC) of angular position. The face of the plastic case contained a 5 in diameter circle of red light emitting diodes (LED) mounted at  $10^{\circ}$  intervals. An additional LED rotated with the knob on a

FIGURE 2. Interior of the anechoic chamber. The speaker ring was mounted at the level of the observer's interaural axis during experimental sessions.



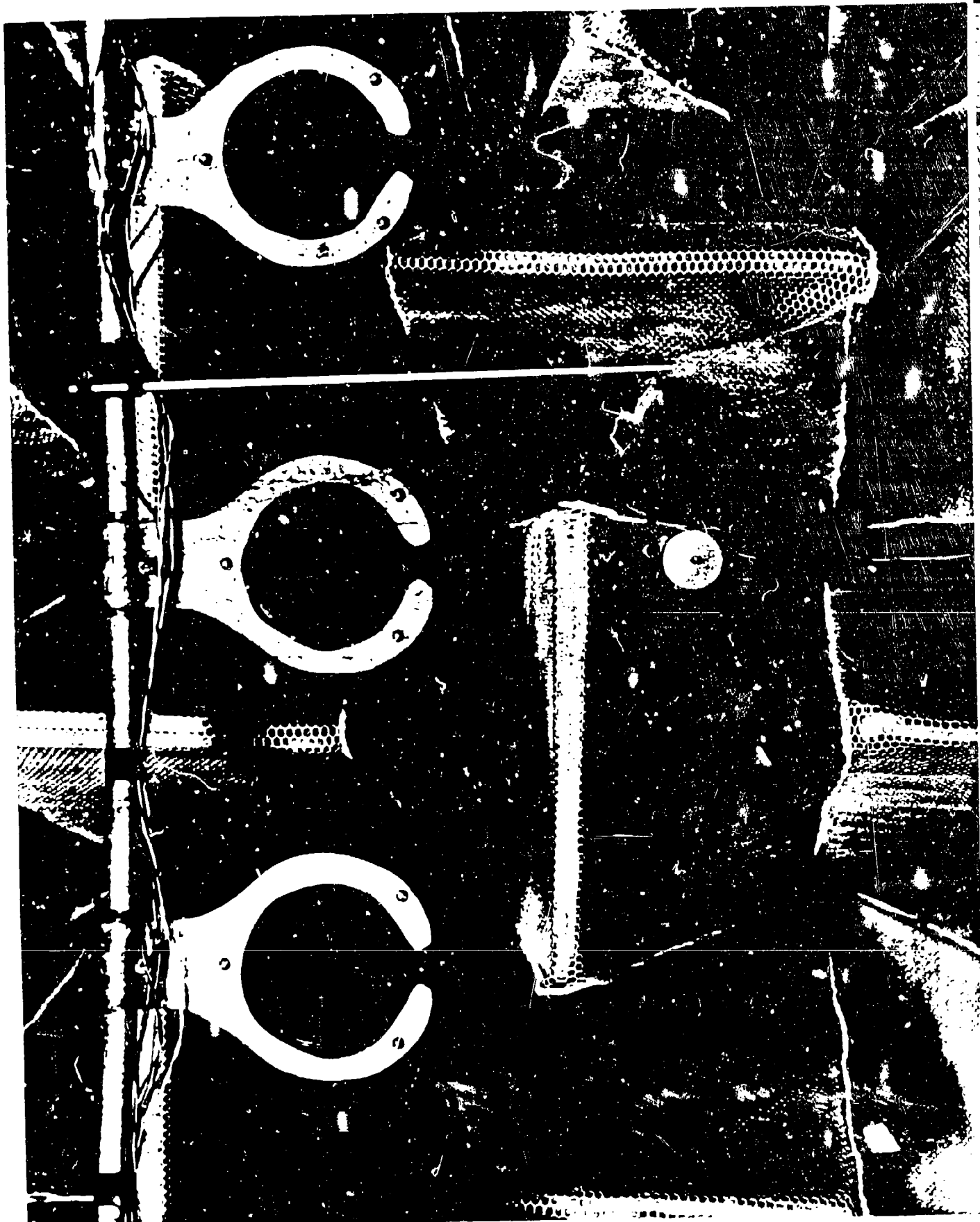
4.75 in diameter circle to indicate relative position to the observer. A push-button was provided on the rim of the case for the subject to indicate completion of a position choice. The response manipulandum was suspended from the subject's chair at a  $30^{\circ}$  angle approximately 10 inches in front of the subject. The response manipulandum is shown in Figure 3. The subject's chair rested on a platform which allowed adjustment of the position of the interaural axis.

FIGURE 3. Response manipulandum which was mounted on the observer's chair.



A visual fixation target (shown in Figure 4), consisting of a red LED showing through a 3 mm orifice 45 mm in front of it, was suspended from the speaker ring. The fixation target provided approximation of Reid's plane (defined by the inferior surface of the bony orbits and the centers of the bony external meatus) with the plane of the speaker circle. The subject wore a pair of sunglasses modified to occlude an approximate  $10^\circ$  object field at a radius of 4.5 ft. Subjects who required corrective lenses for far-field

FIGURE 4. Visual fixation target suspended from the speaker ring.



vision used similarly modified clip-on sunglasses. The locus of the occluded field was adjusted to coincide with the retinal image of the fixation target when the subject's head was correctly oriented. Subjects who exhibited sufficient binocular fusion were given  $10^\circ$  occluded fields over each lens. For subjects who had difficulty fusing the occluded fields, the non-dominant eye was completely occluded. The observers, therefore, had a secondary task of maintaining head orientation by causing the fixation target to disappear. This orientation system was found to control head rotation, flexion and tilt to approximately  $3^\circ$  of tolerance. Figure 5 presents a subject seated in the experimental apparatus wearing a DH-178 helmet. The speaker ring is

FIGURE 5. Subject seated in anechoic chamber, wearing a DH-178 helmet and glasses with completely occluded left lens and  $10^\circ$  occluded spot on right lens. The fixation target (visible in background) was normally mounted at  $0^\circ$  azimuth.



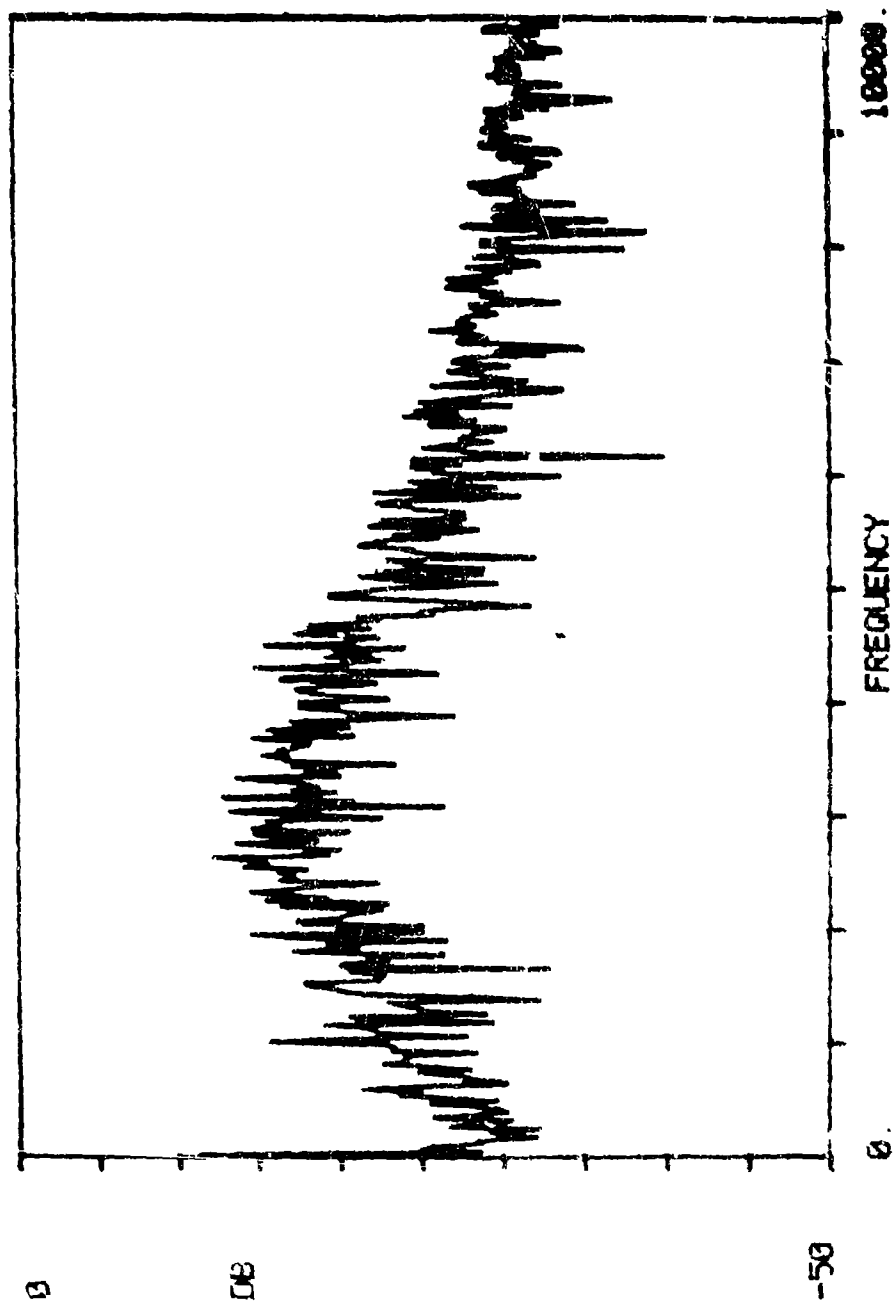


raised and the fixation target (normally directly in front of the subject) can be seen in the background. The subject is wearing sunglasses with a 1<sup>0</sup> occluded field on the right lens and a completely occluded left lens.

The auditory signal consisted of a 750 ms burst of broad-band noise gated with a 10 ms rise/fall time delivered through one of the 36 speakers according to a pseudorandom procedure. Stimuli were presented at a level

FIGURE 6. Average output amplitude spectrum based on 32 samples of 512 points from each of the 36 speakers used in the study.

of 60 dB (re: 20  $\mu$ Pa) measured at the mid-point of the interaural axis without a head in the field. Speakers were selected to optimize similarity of output spectra. An average spectrum of all 36 speakers (Figure 6) was



then used to determine parameters for compensation to approximate a spectrum with constant energy per octave (-3dB slope). The result is shown in Figure 7.

A block diagram of the stimulus generation and calibration systems is shown in Figure 8. Calibration of signal levels measured at each active

FIGURE 7. Average amplitude spectrum for the same speakers measured in Figure 6, after spectral shaping to approximate a -3dB/octave roll off.

component and calibration of temporal parameters was carried out daily. Individual speaker output spectra and average spectrum were measured weekly. No corrections were required over the length of the study.

#### PROCEDURE

All subjects were given pre-training in the experimental tasks without hearing protectors, and at reference azimuths not used in the experimental

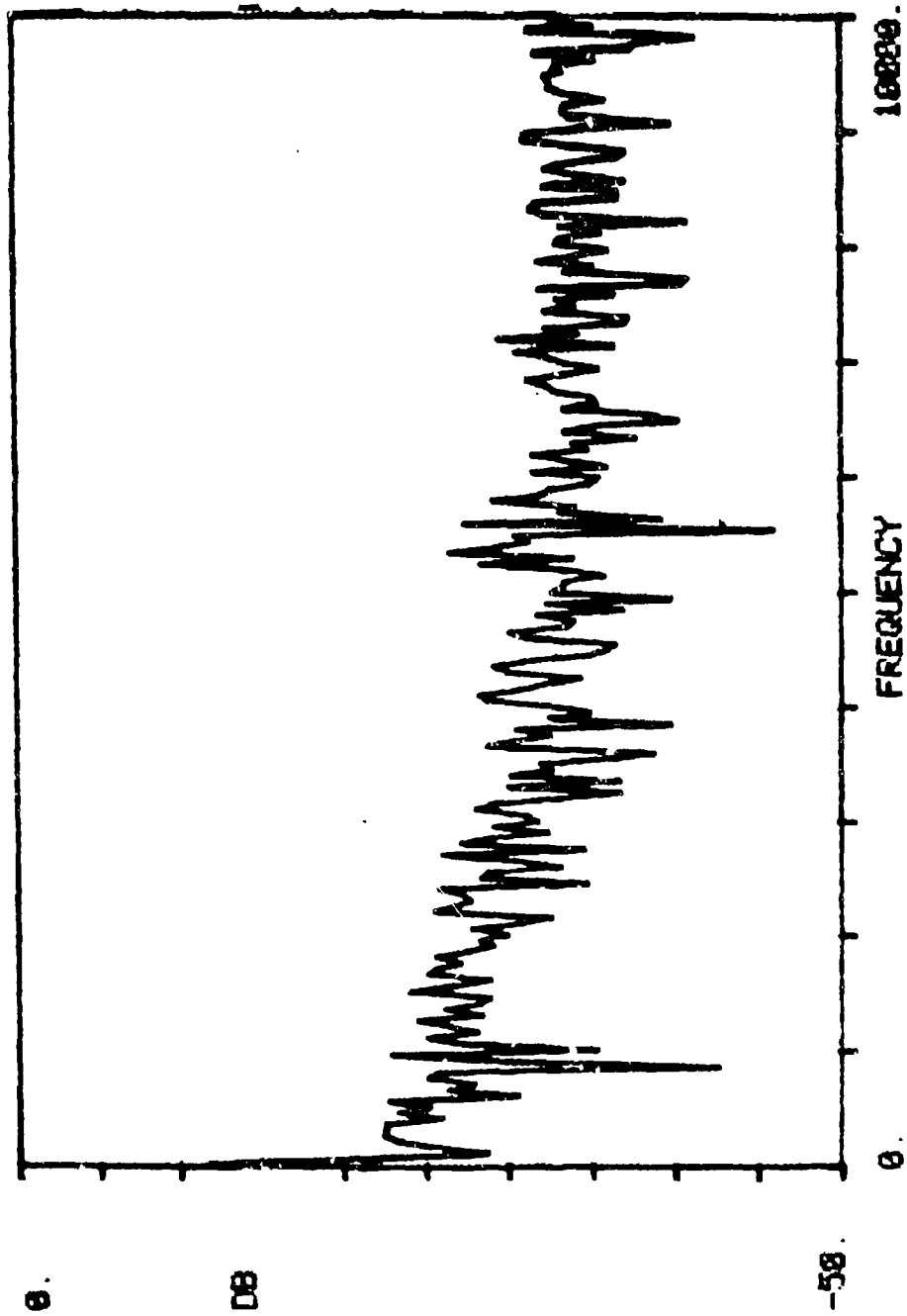
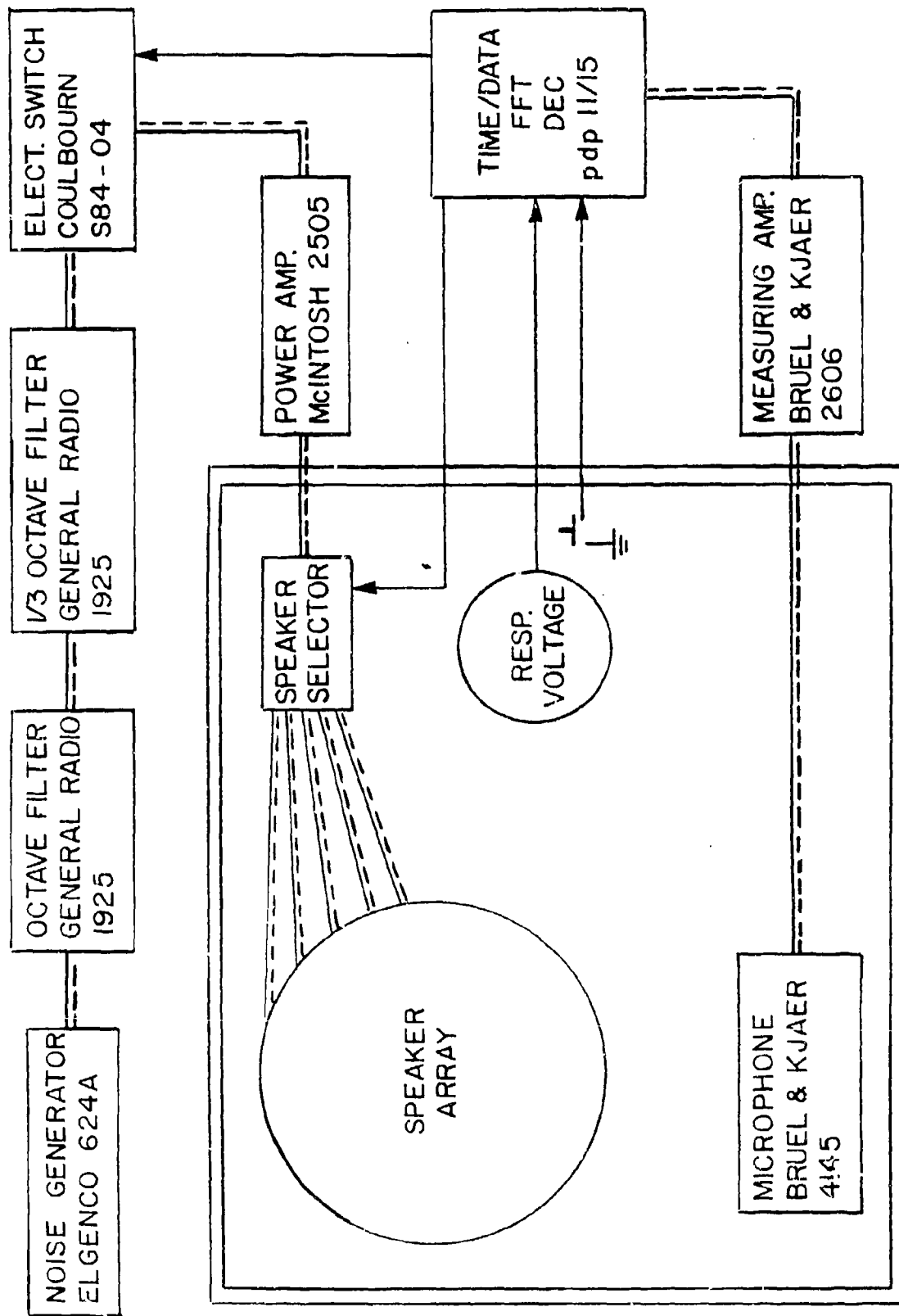


FIGURE 8. Block diagram of the experimental control and calibration systems.

sessions. Practice consisted of 50 to 60 trials for each subject. Each subject made psychophysical observations under five different conditions: no-helmet, DH-178 helmet used in passive mode, DH-178 helmet used in active mode, DH-140 helmet used in passive mode, and DH-140 helmet used in active mode. During observation sessions, the anechoic chamber was dark except for the red light emitted from the response manipulandum and the fixation target. This procedure ensured that the speaker array was not visible. Each session consisted of five trials using each of the 36 speakers in pseudorandom order (sampling without replacement from an array of 180) for a total of 180 trials. Subjects completed 20 sessions in each condition.



ANECHOIC CHAMBER

Fig. 9A

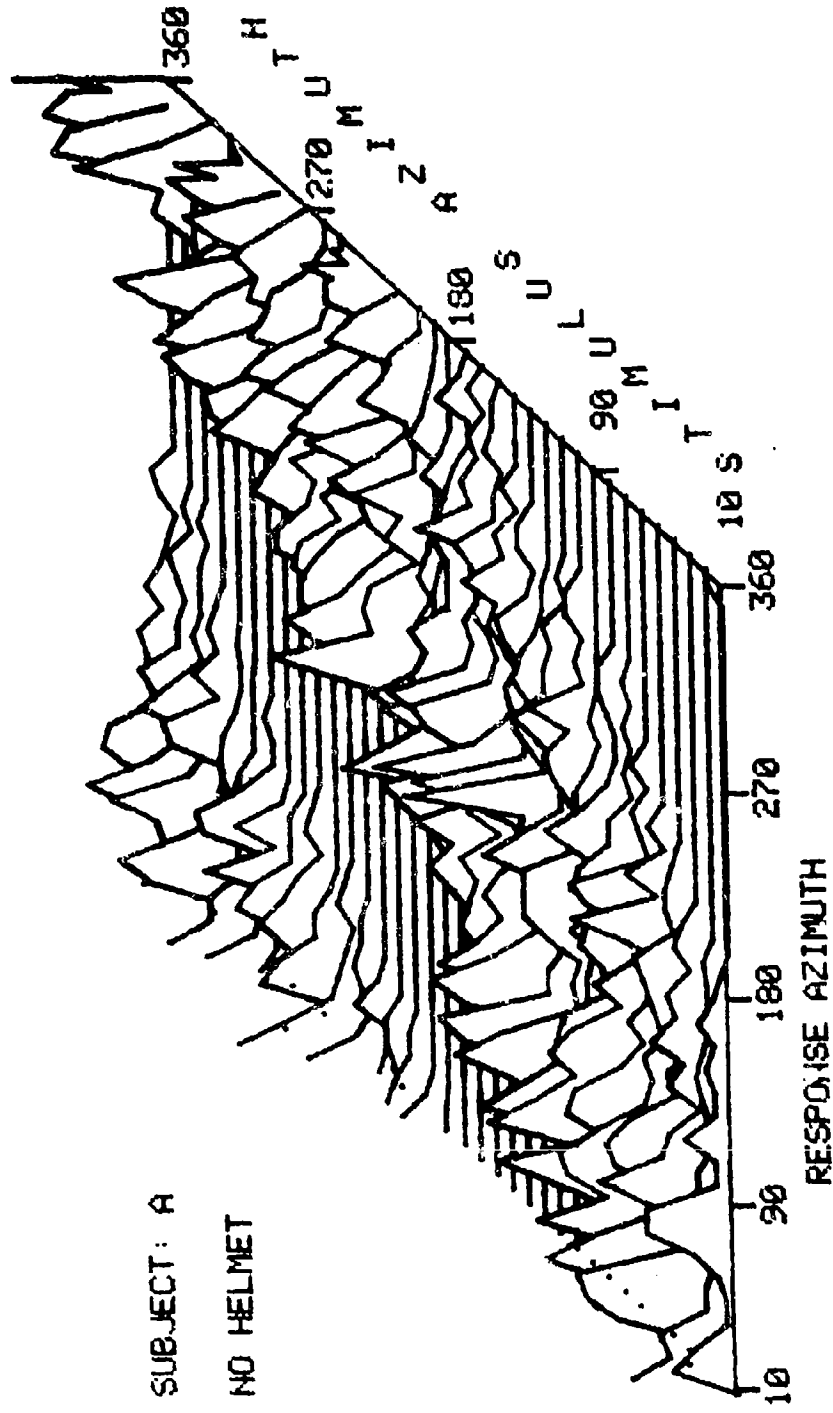
Fig 9B

Fig 9C

FIGURE 9. Response frequency surfaces for each of the six subjects without any hearing protector. Each graph is made up from 36 curves which each contain 100 response choices.

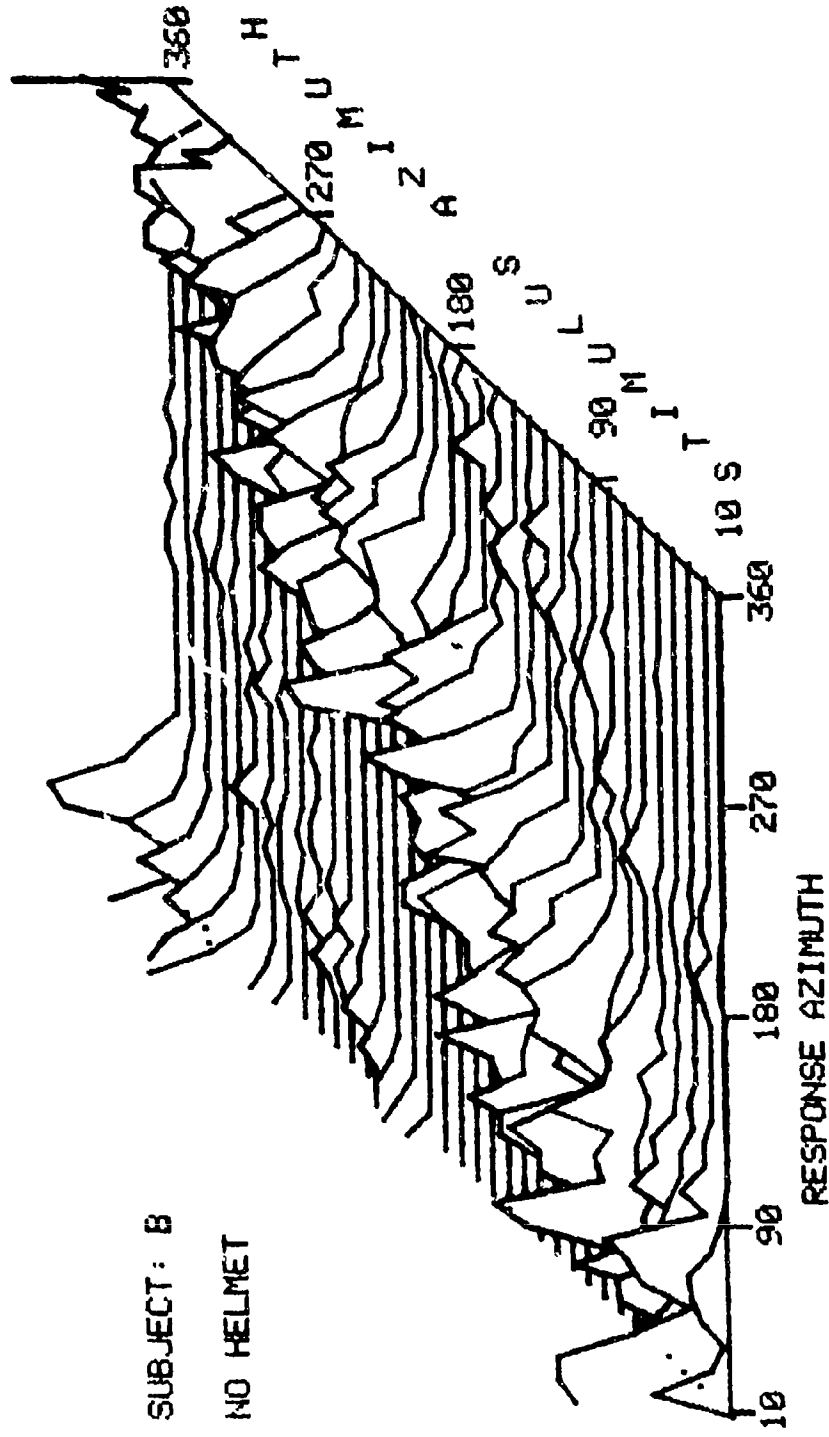


NO HELMET



SUBJECT: B

NO HELMET



SUBJECT: C

NO HELMET

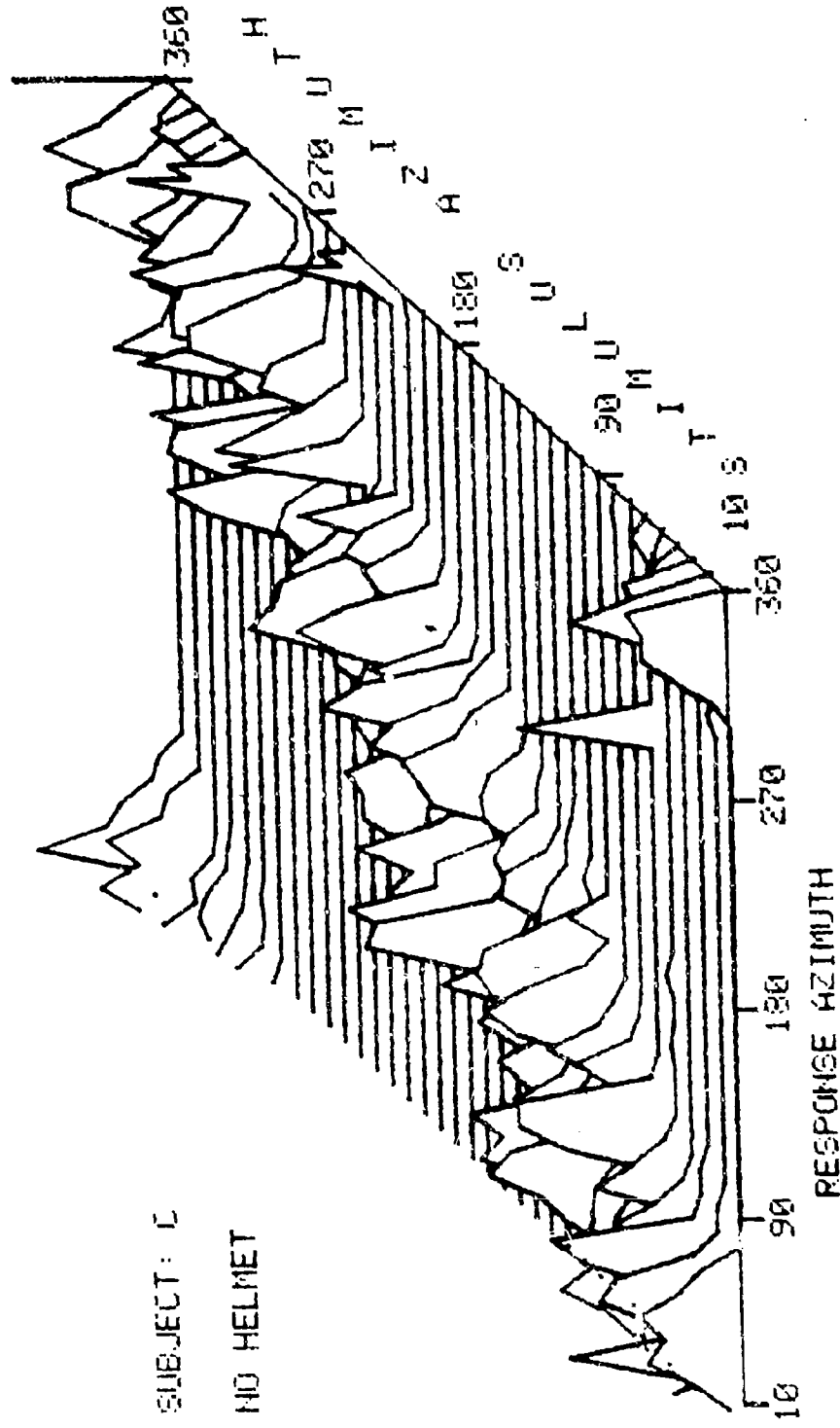


Fig 9D

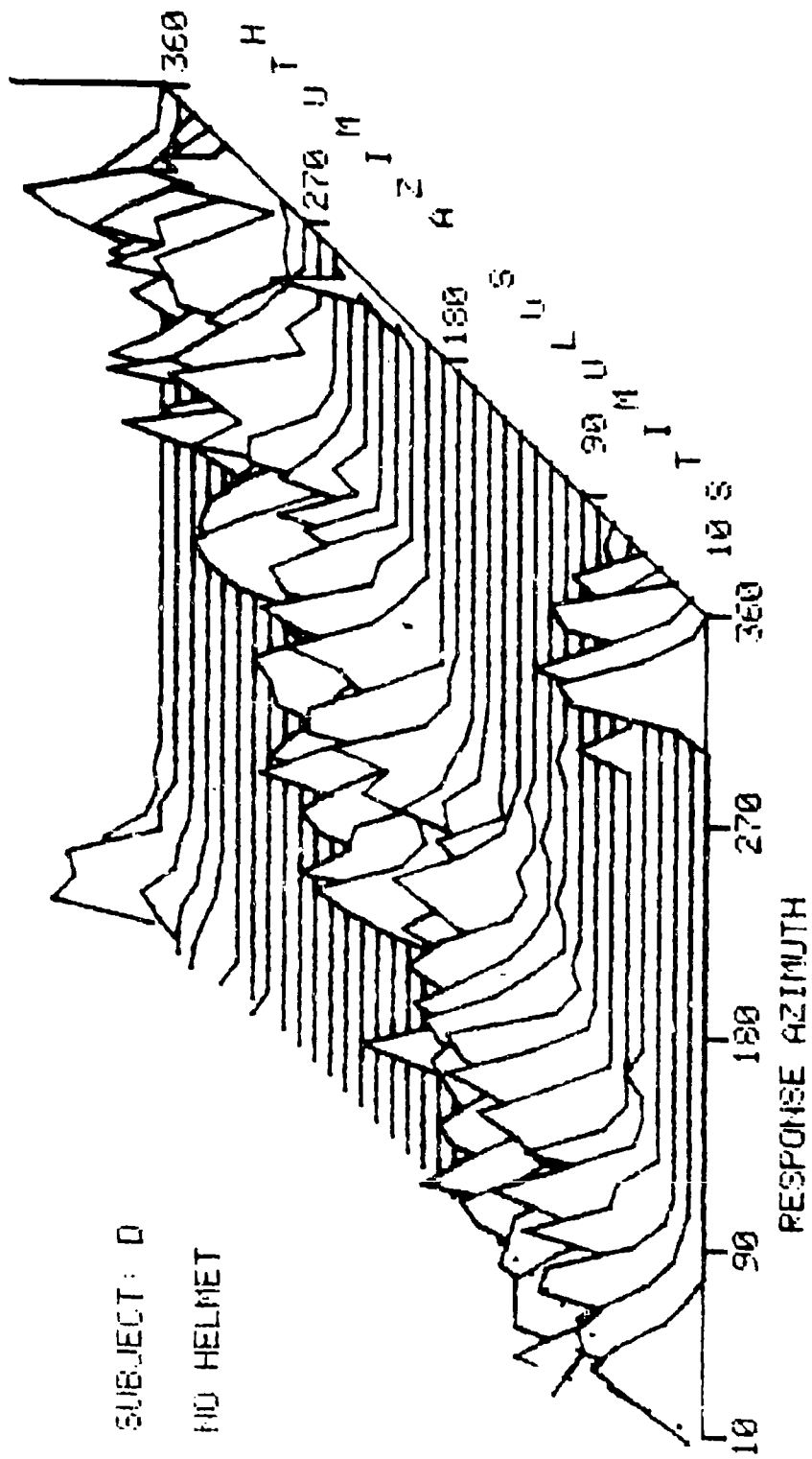
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Fig 9E

Fig 9F

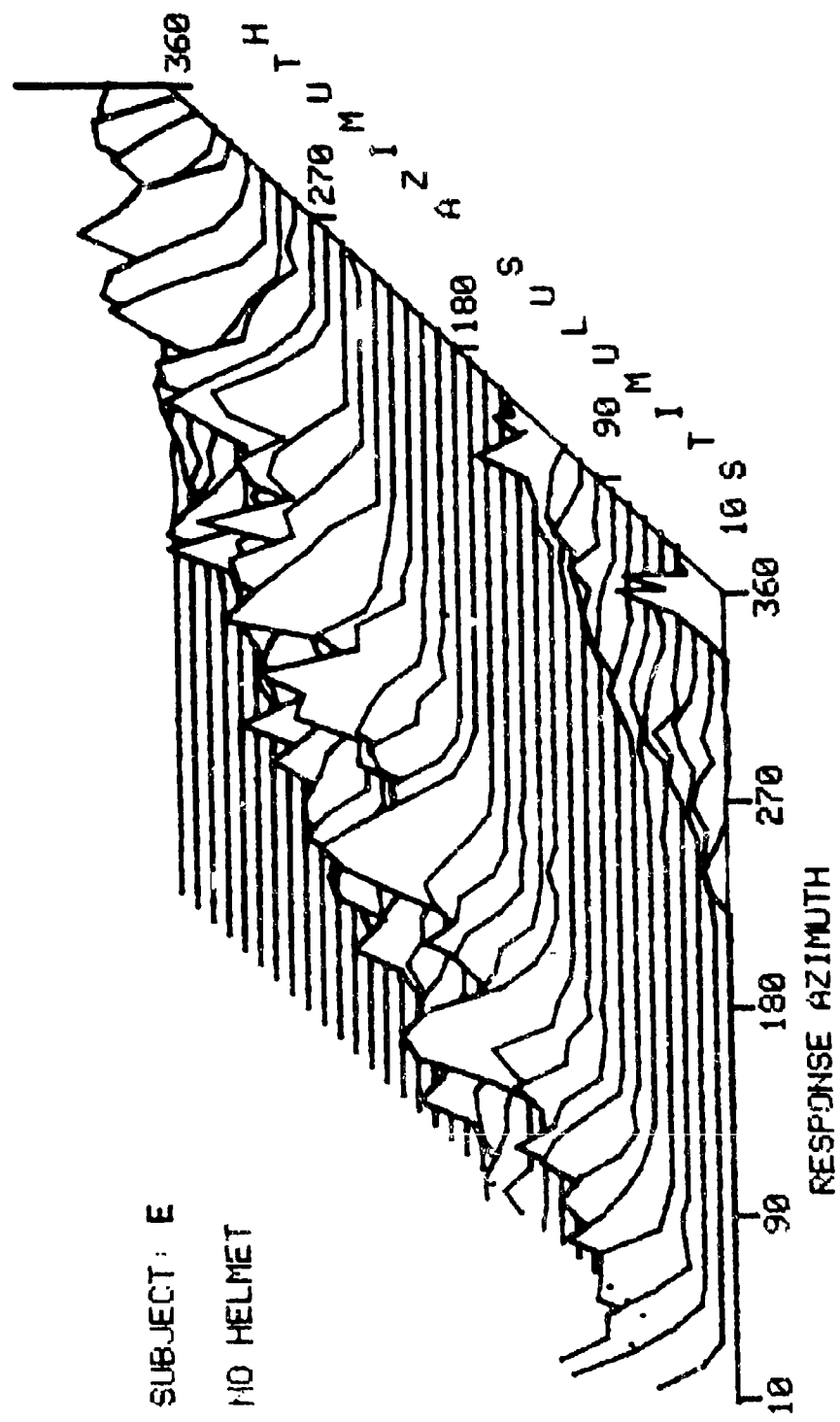
SUBJECT: D

NO HELMET



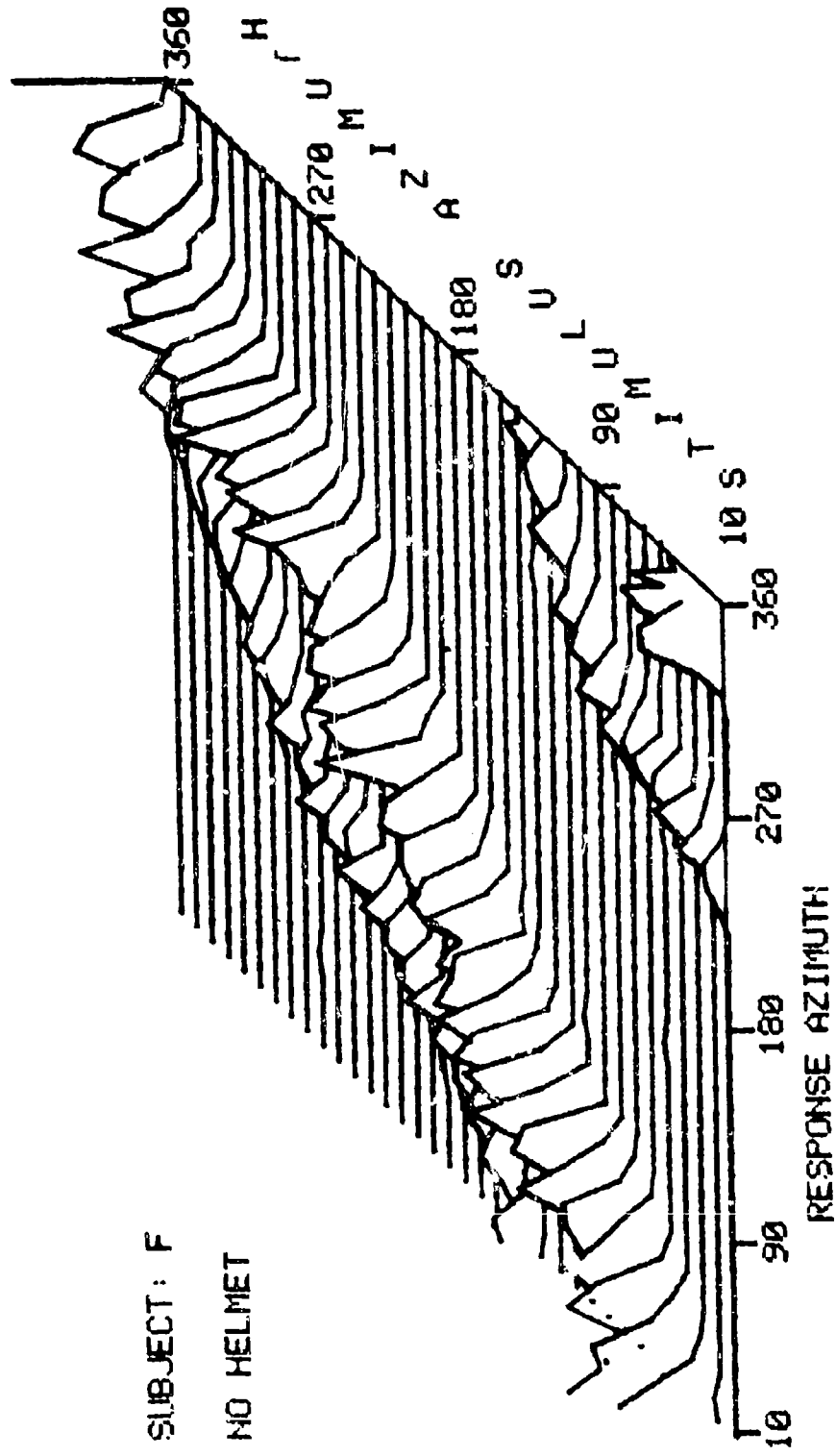
SUBJECT: E

NO HELMET



SUBJECT: F

NO HELMET



A trial was initiated by the subject pressing the button on the rim of the response manipulandum. Following a 1 s interval, a 750 ms burst of noise was presented. The subject was then free to adjust the pointer on the response dial to his best estimate of the azimuthal position of the sound source and initiate the next trial by pressing the button again. The primary task of the subject was to respond in a self-paced stimulus identification paradigm. The secondary task was to maintain head orientation by occlusion of the visual target. An average trial was completed in slightly less than 2 s.

To minimize association of possible speaker signatures with azimuthal loci, the relative referent azimuth ( $0^{\circ}$ ) was changed to a randomly selected absolute azimuth at least once in each condition for each subject. This was accomplished by moving the fixation target and rotating the chair platform between sessions.

## RESULTS

Response voltages recorded from each trial were translated into azimuth angle and rounded to the nearest  $10^{\circ}$ . These response values were sorted by their associated stimulus azimuths and plotted in  $36 \times 36$  point integer matrices, one for each observer in each of the five conditions.

Figure 9 presents the resulting graphs for observations made by each of the six subjects in the control (no-helmet) condition. In general, it is clear that apparent azimuth followed stimulus azimuth and that responses within subjects exhibit a fairly consistent degree of variability across stimulus azimuth. Subject A was more variable in responding than other subjects and shows a partial response bias as indicated by a consistent clockwise trend of confusion. Subject B, though less variable, also shows some bias in responding.

Patterns of responding produced by subjects C and D closely followed stimulus locus with very little directional bias. Two anomalous features are common to the plots for subjects C and D. One appears as an isolated peak at a response azimuth of  $260^{\circ}$  and stimulus azimuth  $60^{\circ}$ . The other is a more complex peak centered at a response azimuth of  $350^{\circ}$  and stimulus azimuth  $230^{\circ}$ . Although two different reference azimuths were used in this condition, subjects C and D used the same referents. Therefore, it is suggested that these anomalous features may be the result of previously unaccounted speaker signature differences or reflections within the anechoic chamber. Subjects E and F also show response patterns closely following stimulus locus and show a slight counter-clockwise response bias.

Plots for observations made by the six subjects while wearing the DH-178 helmet used in passive mode are shown in Figure 10. Clearly, for subjects A, B, C and D, the apparent loci of the sound sources consistently



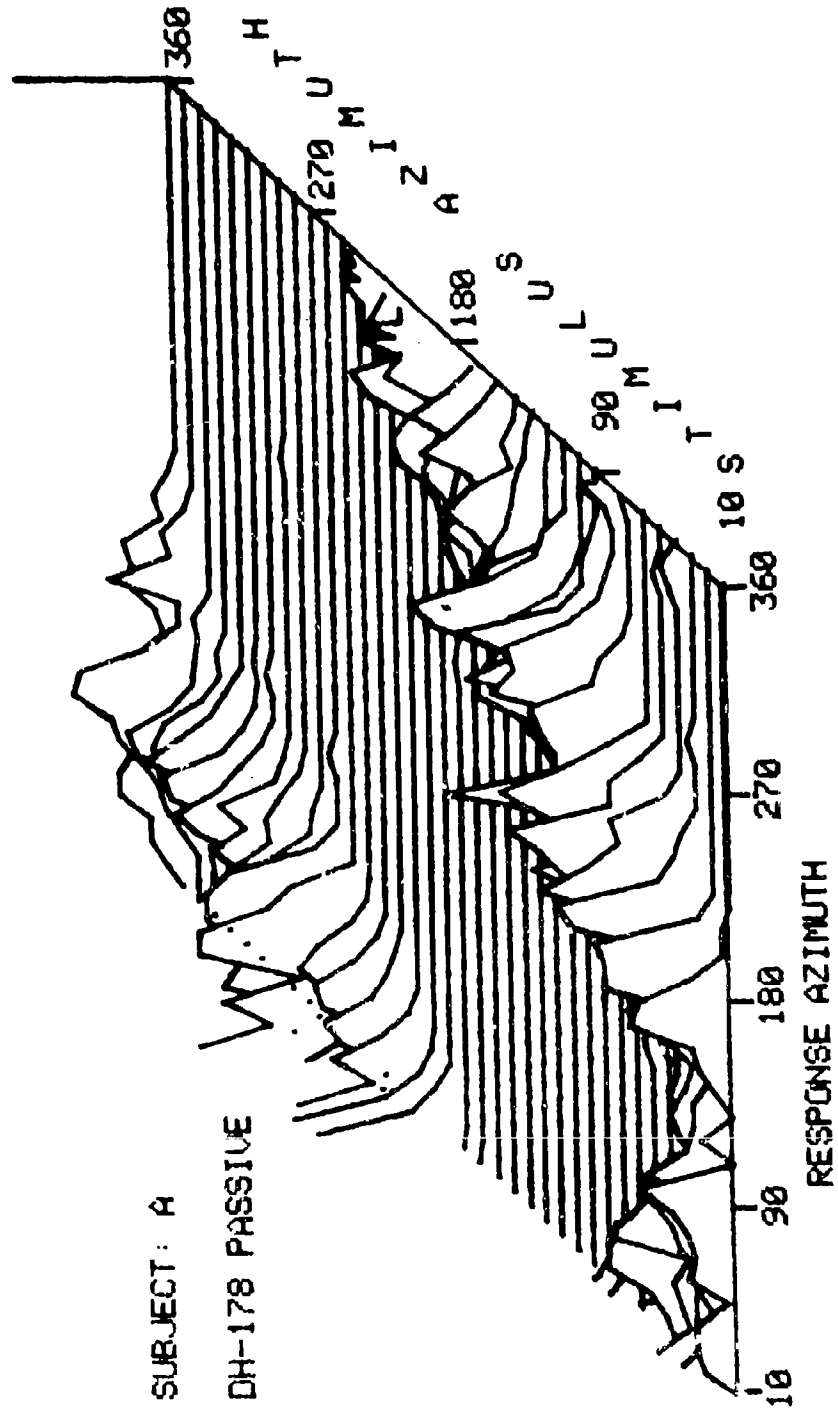
Fig. 10A

Fig. 10B

Fig. 10C

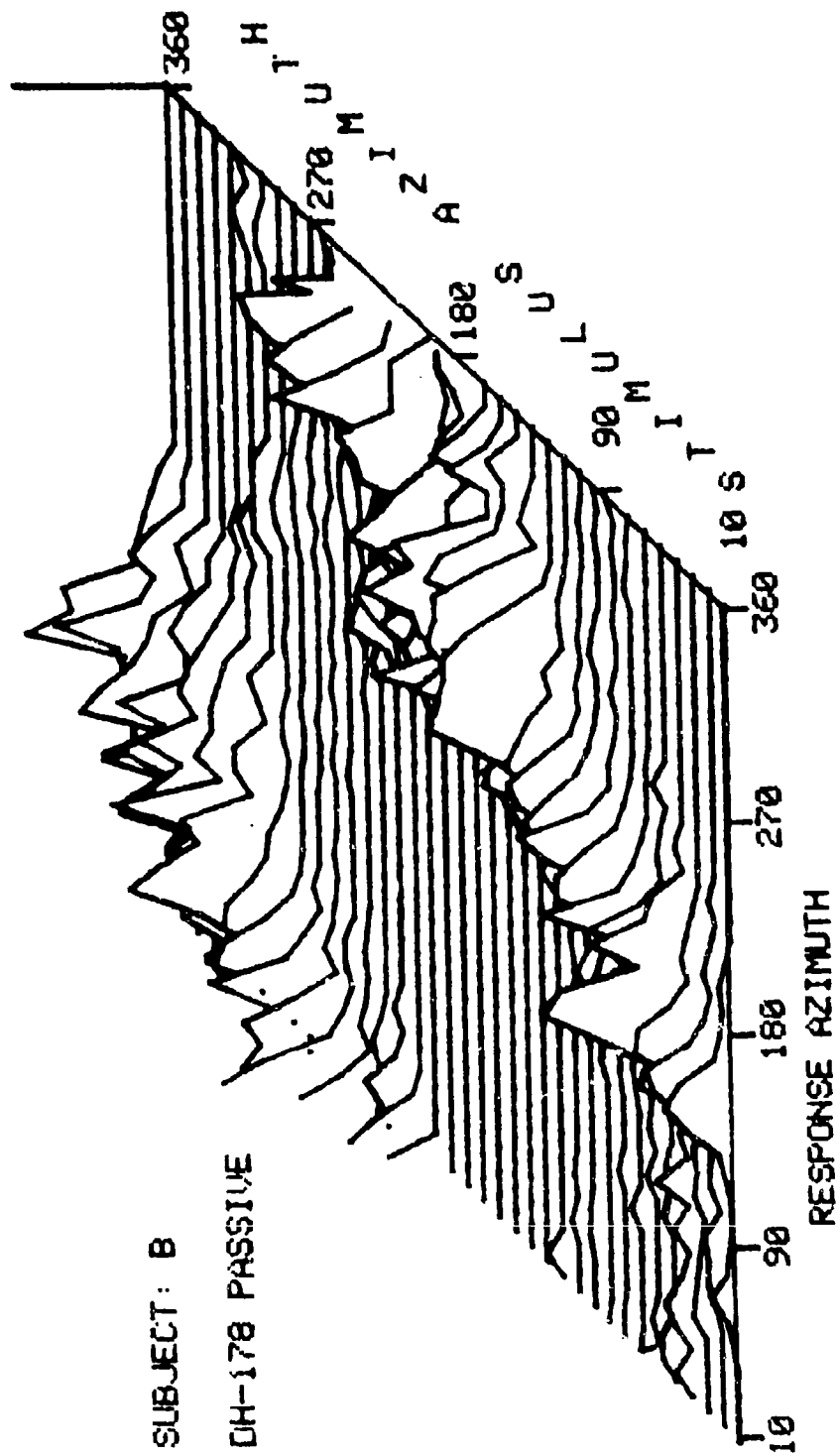
FIGURE 10. Response frequency surfaces for the six subjects while using the DH-178 helmet in passive mode.

SUBJECT: A  
DH-178 PASSIVE



SUBJECT: B

DH-178 PASSIVE



SUBJECT: C

CH-178 PASQUE

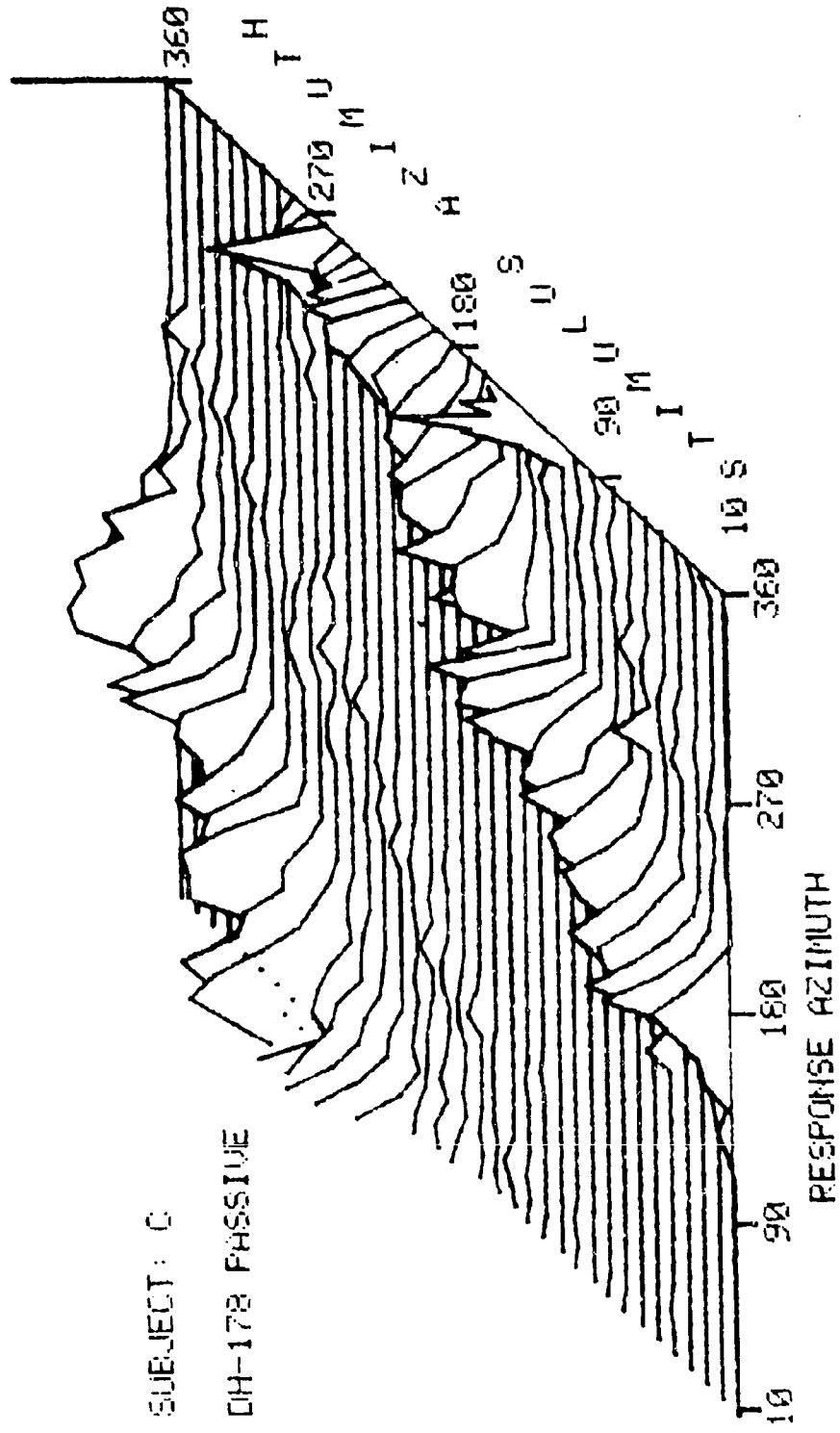


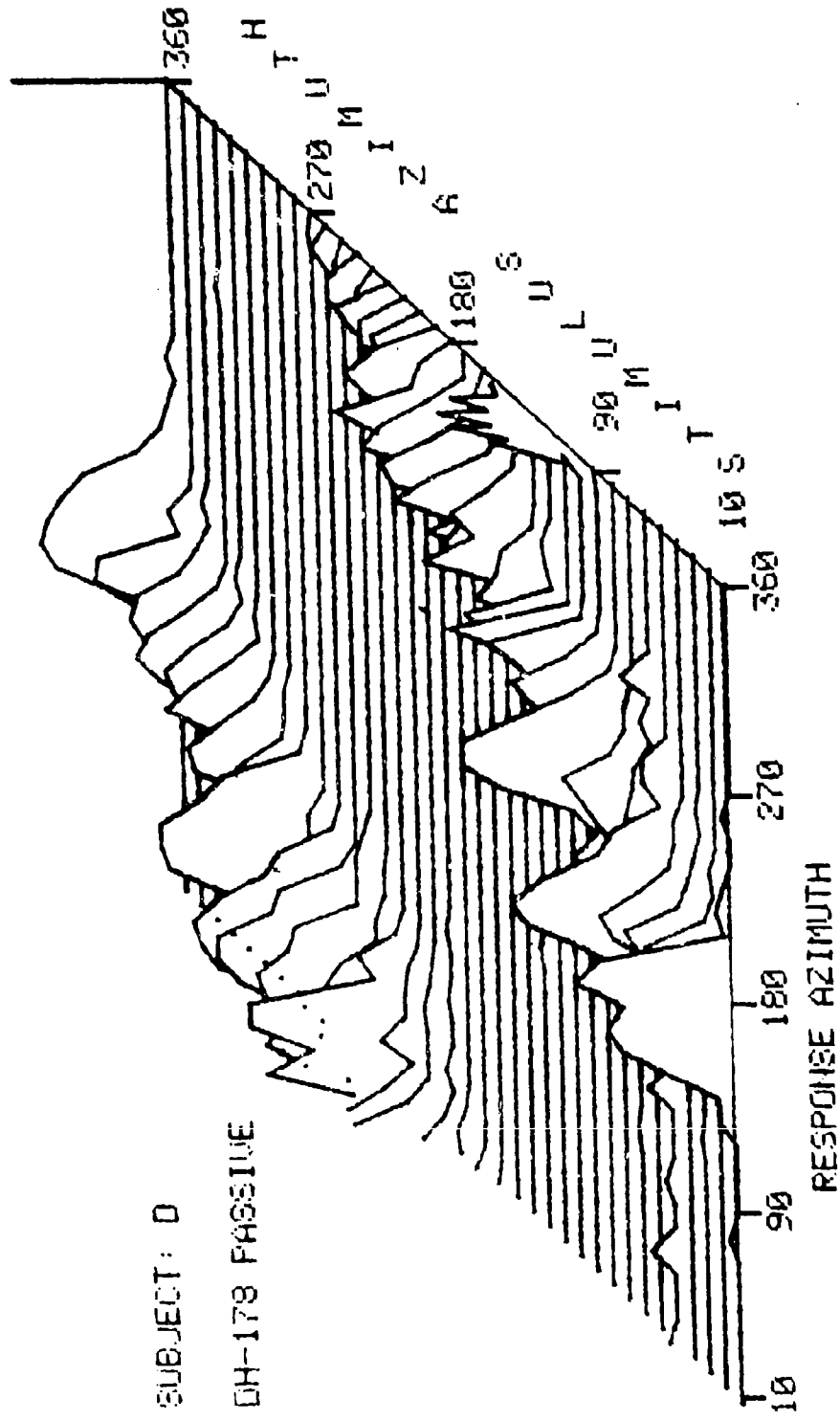
Fig. 10D

Fig. 10E

Fig. 10F

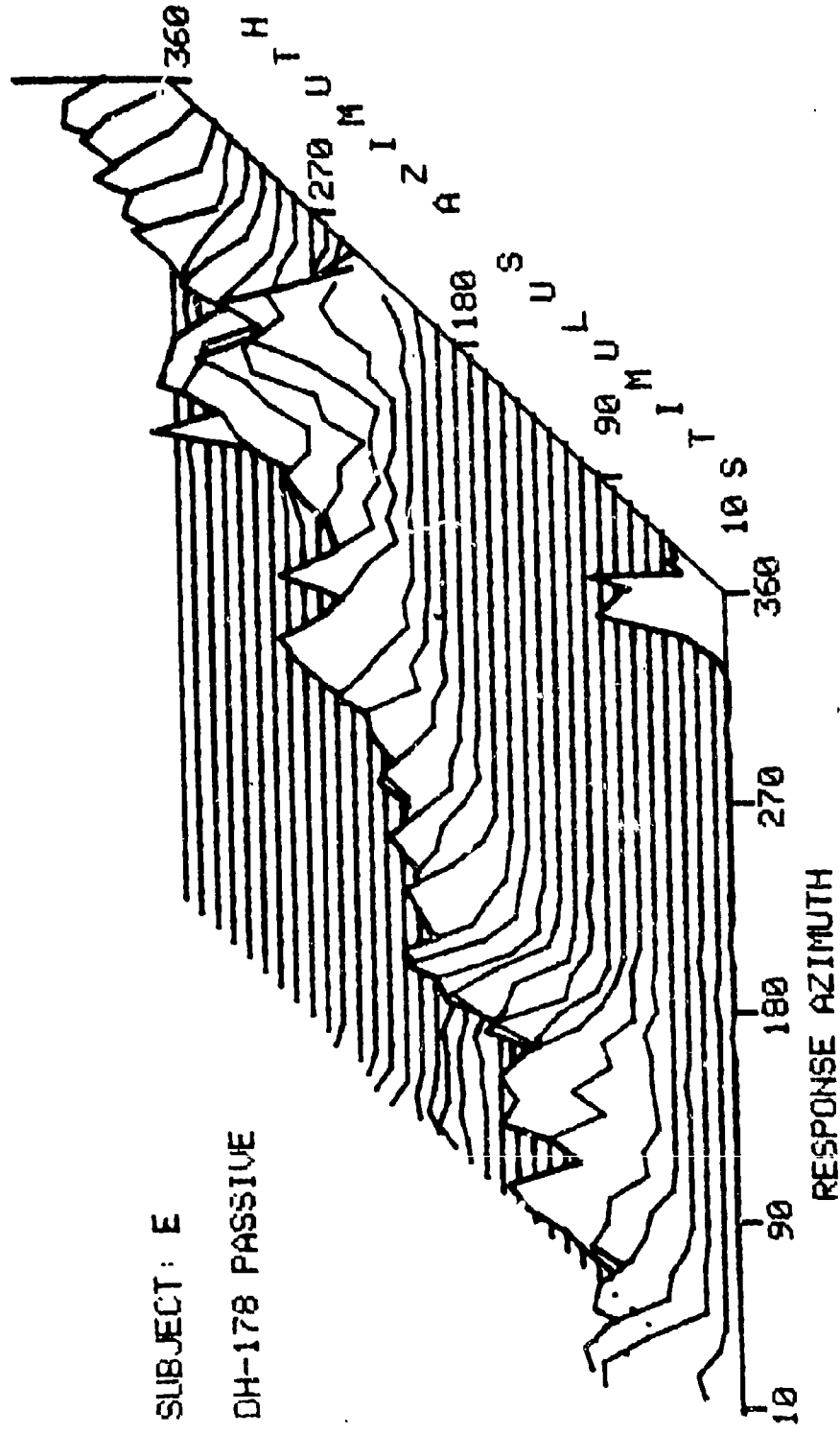
SUBJECT: D

DH-178 PASSIVE

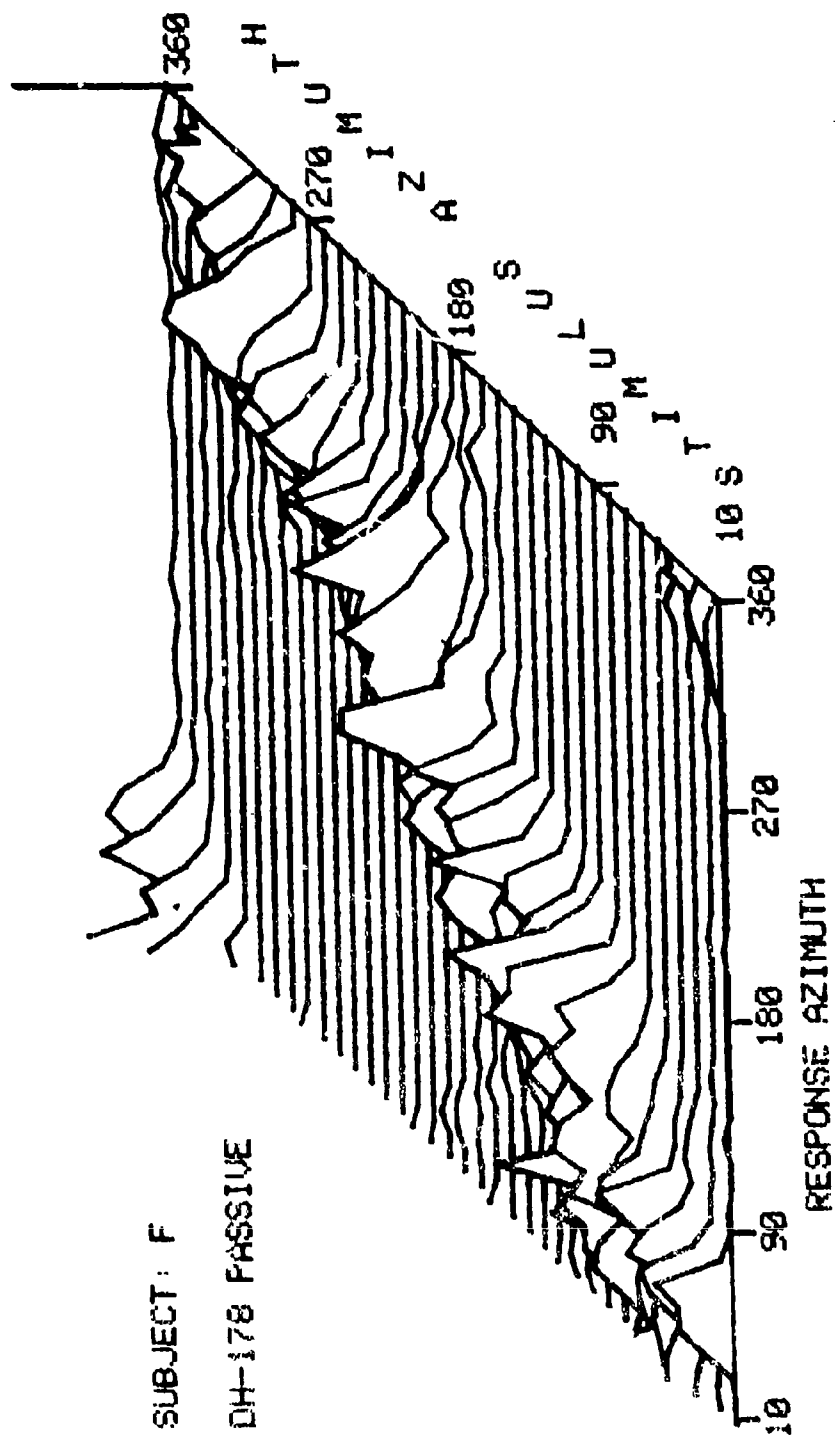


SUBJECT: E

DH-178 PASSIVE



SUBJECT: F  
DH-178 PASSIVE





were nearly  $180^{\circ}$  from their physical loci. Subjects C and D again produced a common anomalous feature, a complex peak centered at a response azimuth of  $360^{\circ}$  and stimulus azimuth of  $120^{\circ}$ .

Azimuth identification by subjects E and F appears to have been not greatly affected by the introduction of the DH-178 helmet. Subject E appears to have had some tendency to confuse sound sources behind the interaural axis with sources in front of the interaural axis. This is indicated by the distortion of the central ridge in the plot, particularly where stimuli were located near  $90^{\circ}$  or  $270^{\circ}$ .

A more complex pattern of responding emerged when the DH-178 helmet was used in active mode. In Figure 11, which contains plots of data for this condition, a serpentine pattern is prevalent. All six subjects exhibited a marked decrement in assigning loci in front of the interaural axis. It is also clear that stimuli arising from one side of the midsagittal plane were often identified as arising from the opposite side.

Subjective reports from all six observers agreed that stimuli presented when the DH-178 helmet was used in active mode were not localized in external auditory space but were perceived as internal to the head (or occasionally inside the helmet). Furthermore, the apparent internal locus of stimuli varied little even though qualitatively different stimuli were identifiable. Since the subject was forced to locate the source on an analog to external space, the results may indicate an arbitrary projection of the internalized image rather than a systematic relationship between source and perception.

Figure 12 contains plots of observations made with the DH-140 helmet used in passive mode. Azimuth identification for subject A appears to have been minimally affected by introduction of this helmet. Responses by this subject followed stimulus azimuth reasonably well. A partial counter-clockwise response bias is evident. Other subjects appear to have responded in patterns similar to those found when the DH-178 helmet was used in passive mode. Responses generally appear to be rotated approximately  $180^{\circ}$  with regard to stimulus azimuth.

Use of the DH-140 helmet in active mode resulted in the response patterns shown in Figure 13. Subjective reports again agreed that stimuli were localized inside the head. Responses in this condition are forced assignments to external space.

The decrement in assignment of loci behind the interaural axis is obvious. Clearly, the range of responding is reduced. Most stimuli were identified as directly or nearly directly ahead regardless of physical source azimuth. Subjects A, E and F did assign some stimuli a locus directly behind the head but for subjects A and E that assignment is negatively correlated with stimulus azimuth. Subjects C and D identified some stimuli to the right of the midsagittal plane and subject F identified a few to the left of the midsagittal plane.

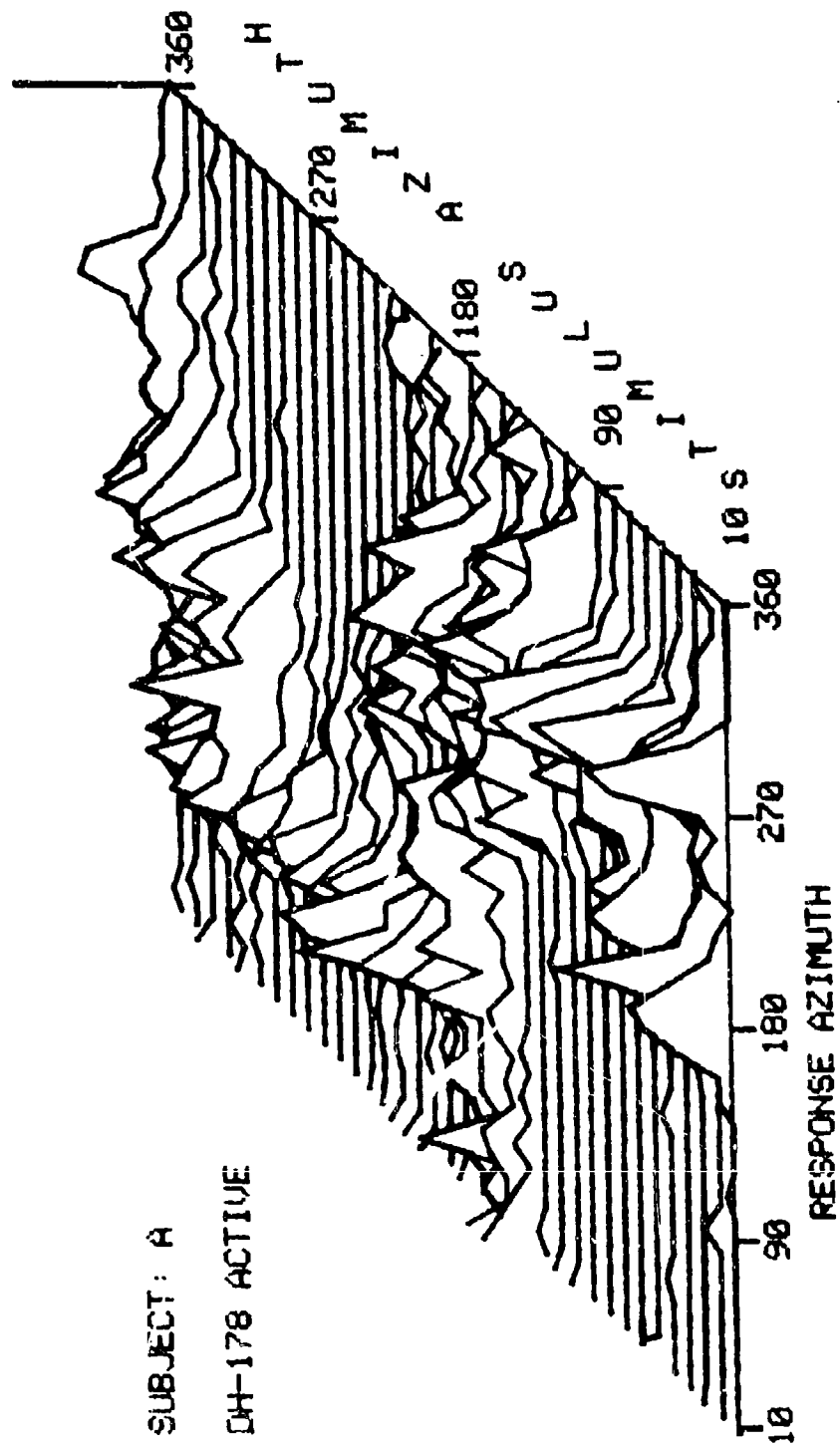
Fig. 11A

Fig. 11B

Fig. 11C

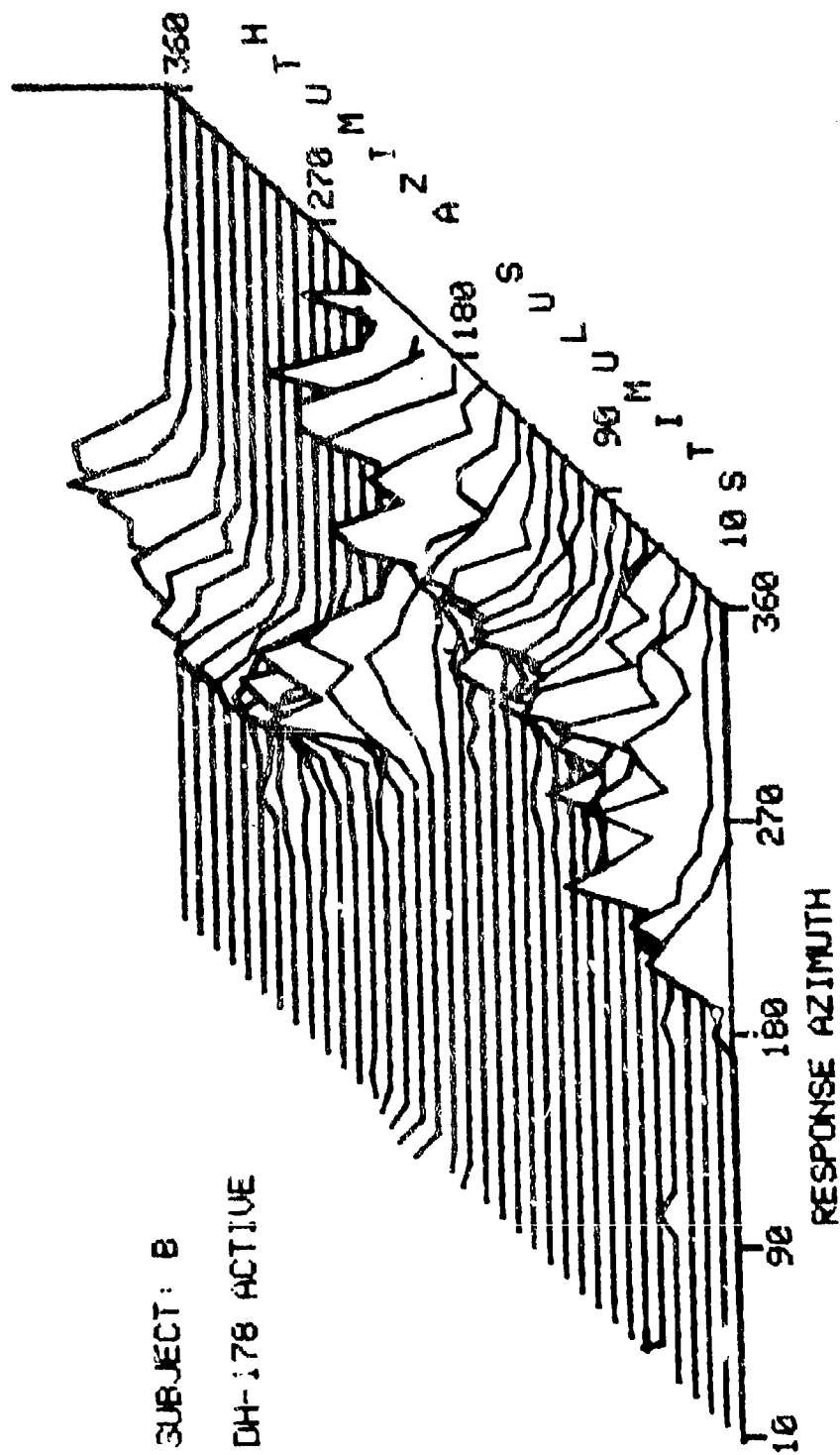
FIGURE 11. Response frequency surfaces for the six subjects using the DH-178 helmet in active mode.

**QH-178 ACTIVE**



SUBJECT: B

DH-178 ACTIVE



SUBJECT: C  
DH-178 ACTIVE

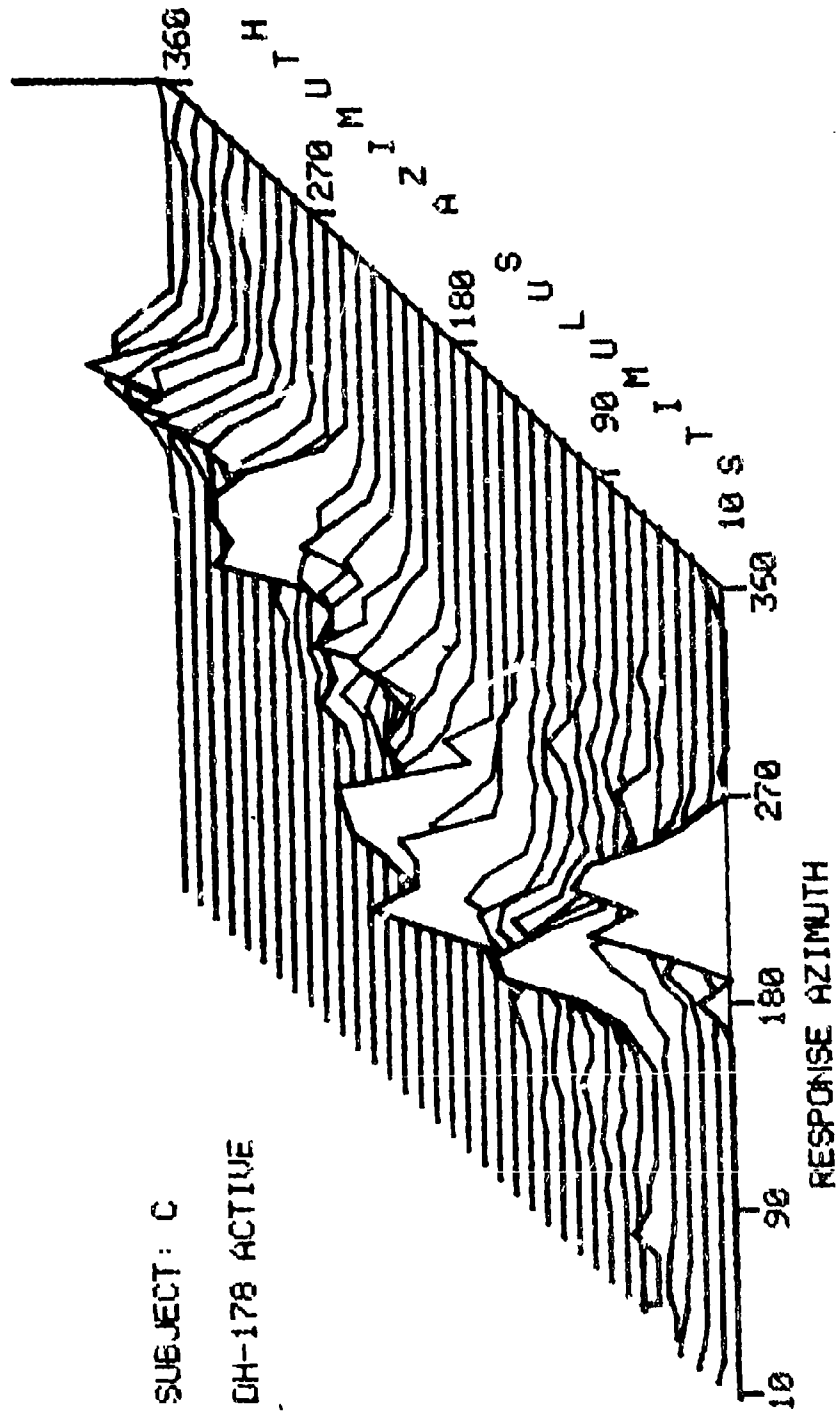
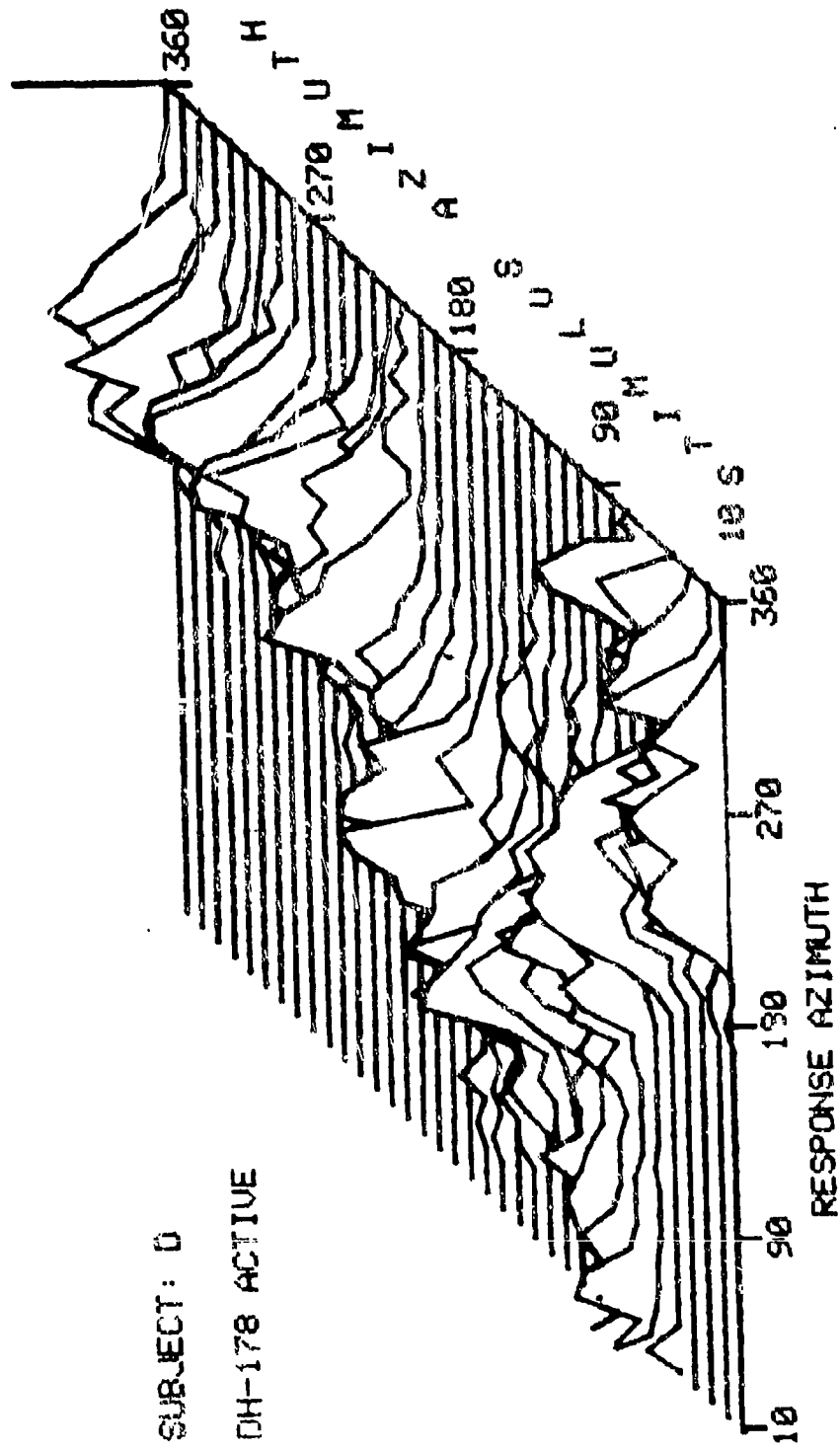


Fig. 11D

Fig. 11E

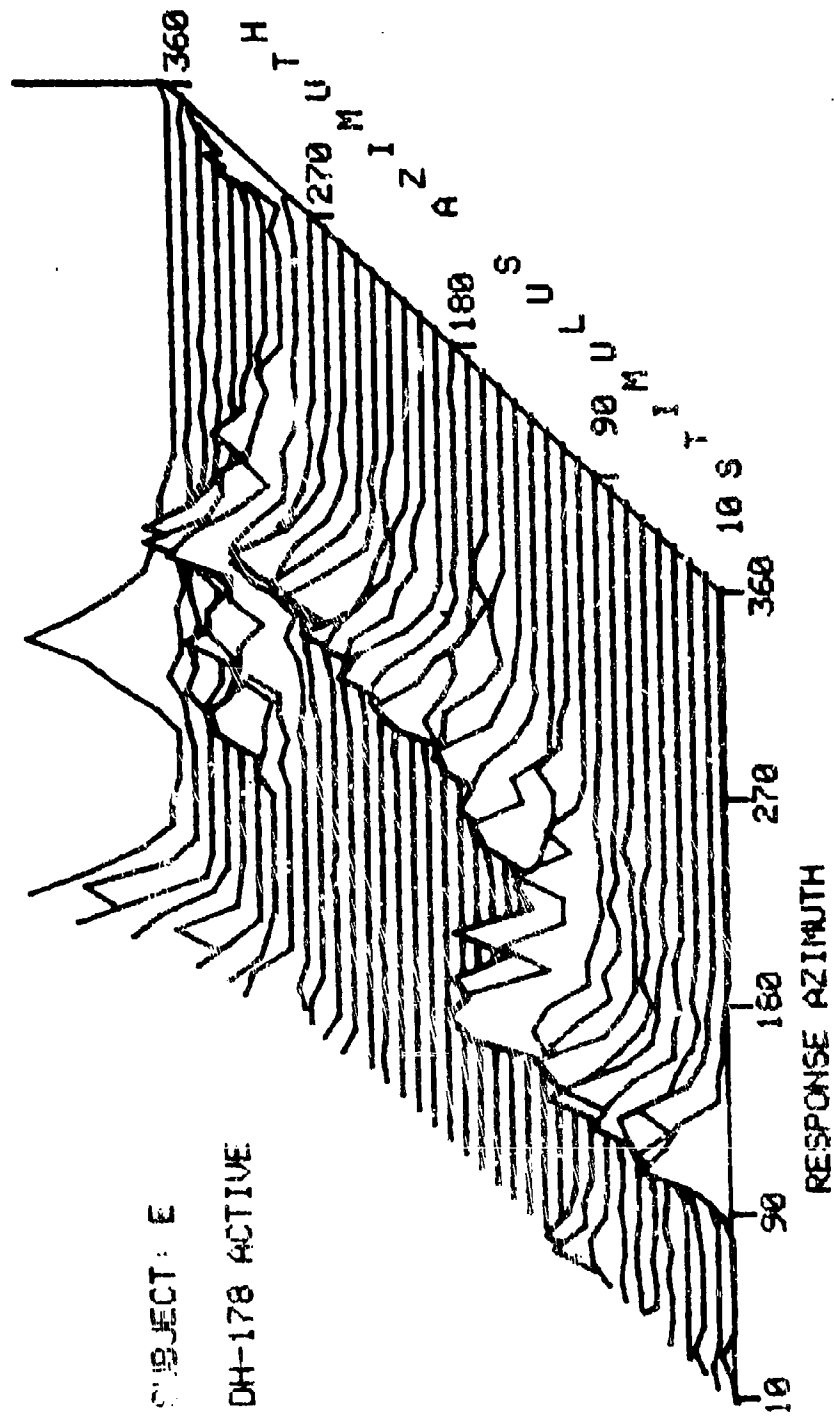
Fig. 11F

SUBJECT: U  
DH-178 ACTIVE



100

04-178 ACTIVE





SUBJECT: F  
DH-178 ACTIVE

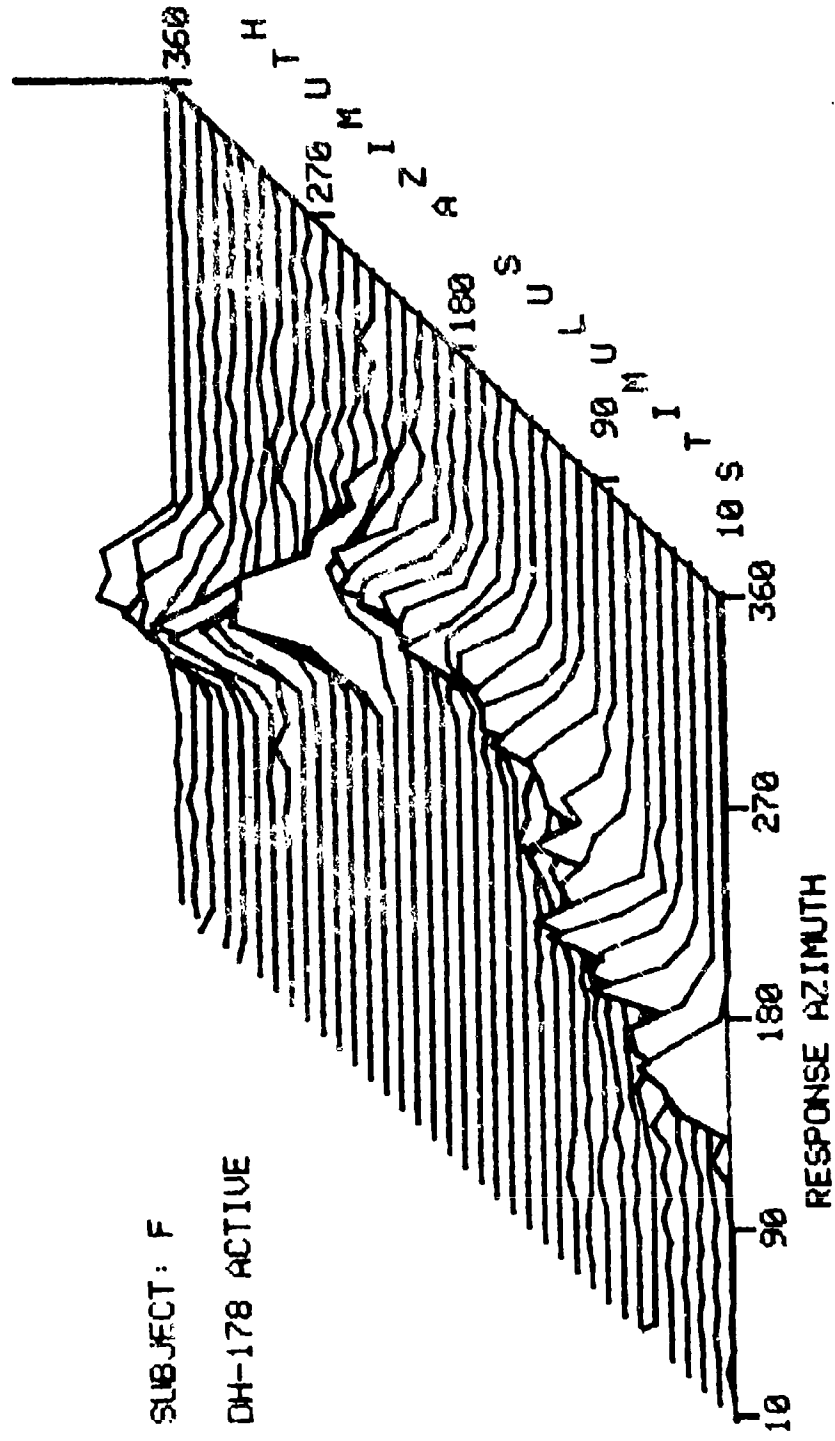


Fig. 12A

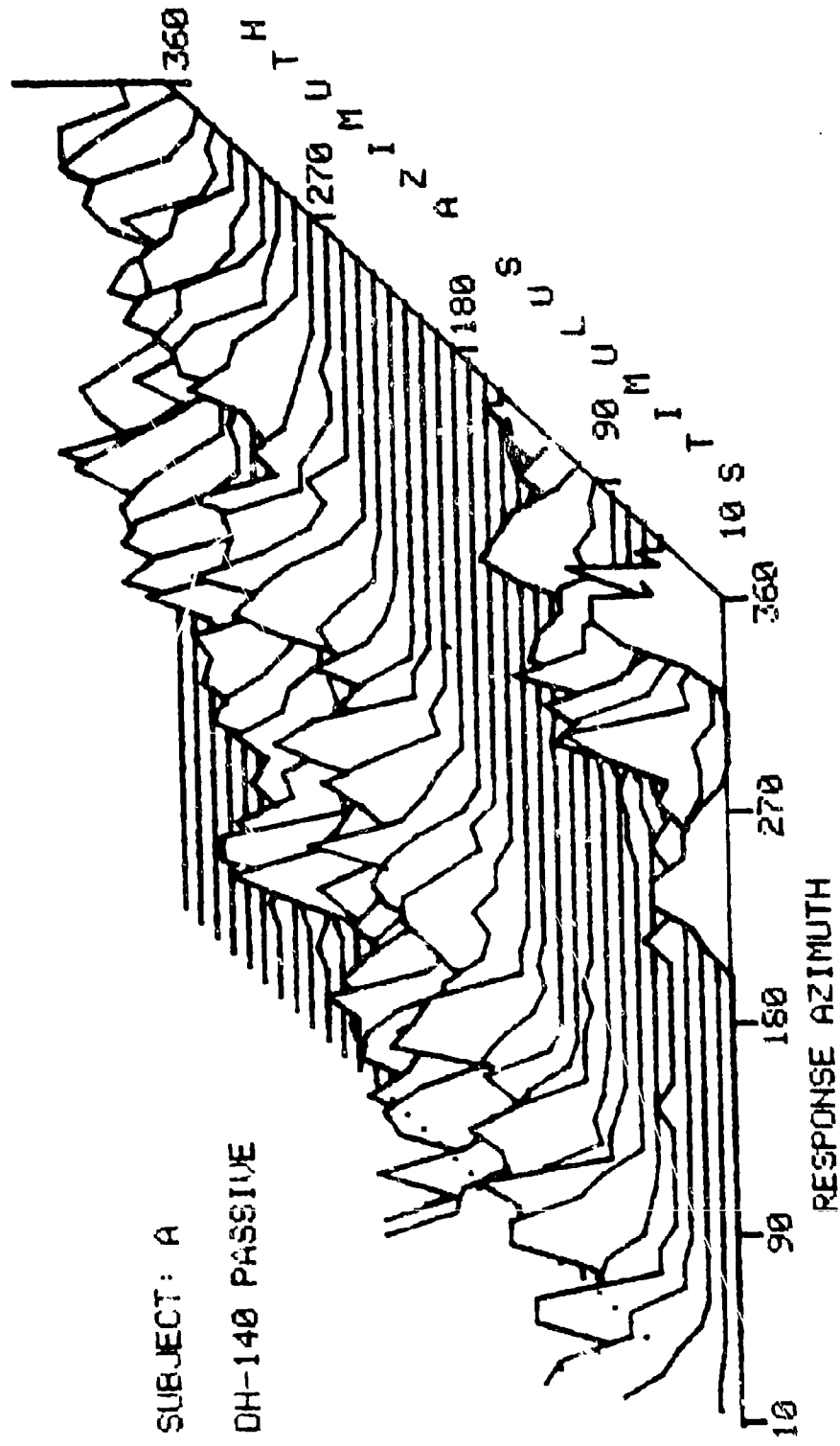
Fig. 12B

Fig. 12C

FIGURE 12. Response frequency surfaces for the six subjects using the DH-140 helmet in passive mode.

SUBJECT: A

DH-140 PASSIVE



SUBJECT: B  
DH-140 PASSIVE

RESPONSE AZIMUTH

RESPONSE ELEVATION

RESPONSE AZIMUTH

SUBJECT: C  
DH-140 PASSIVE

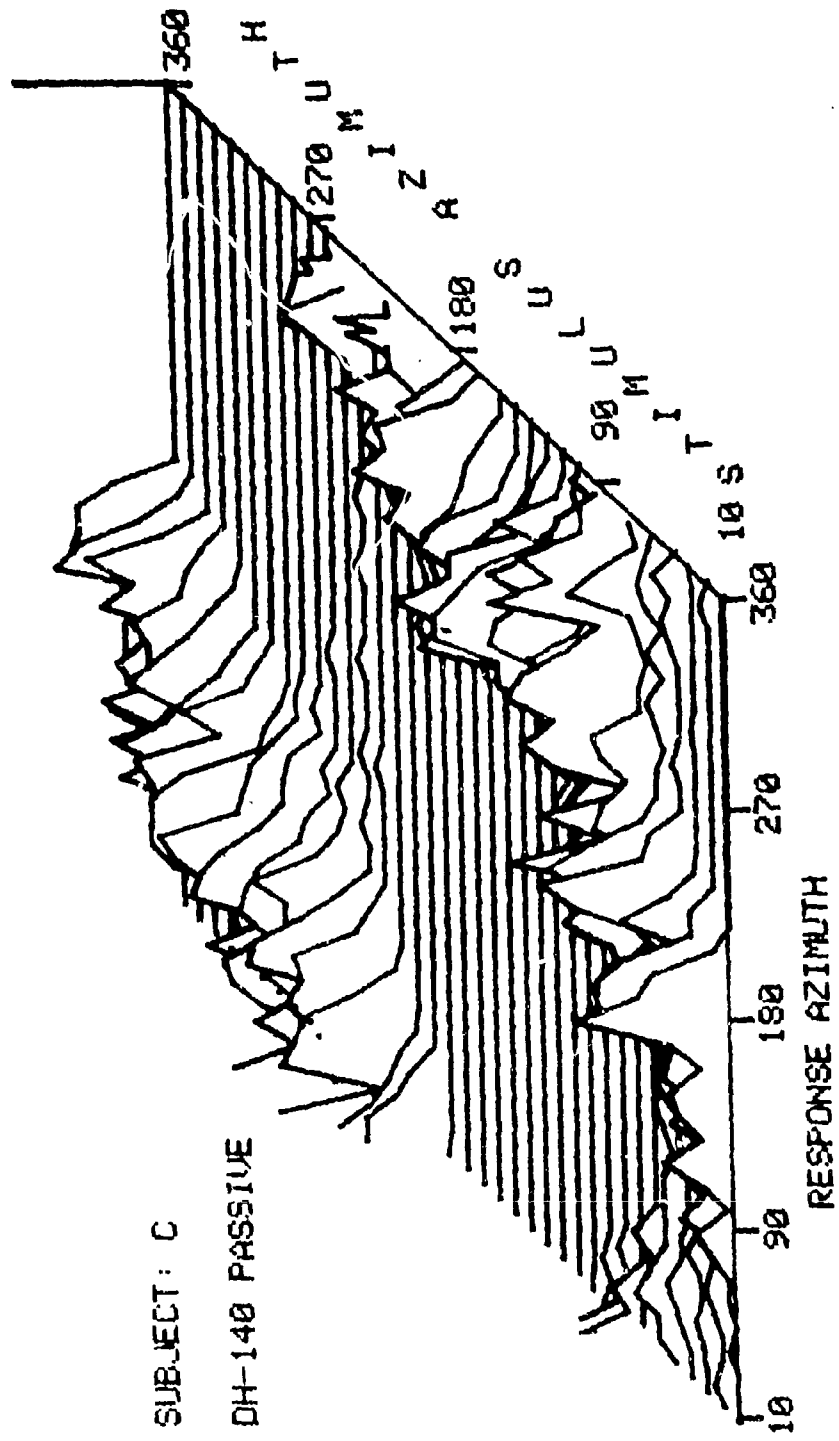


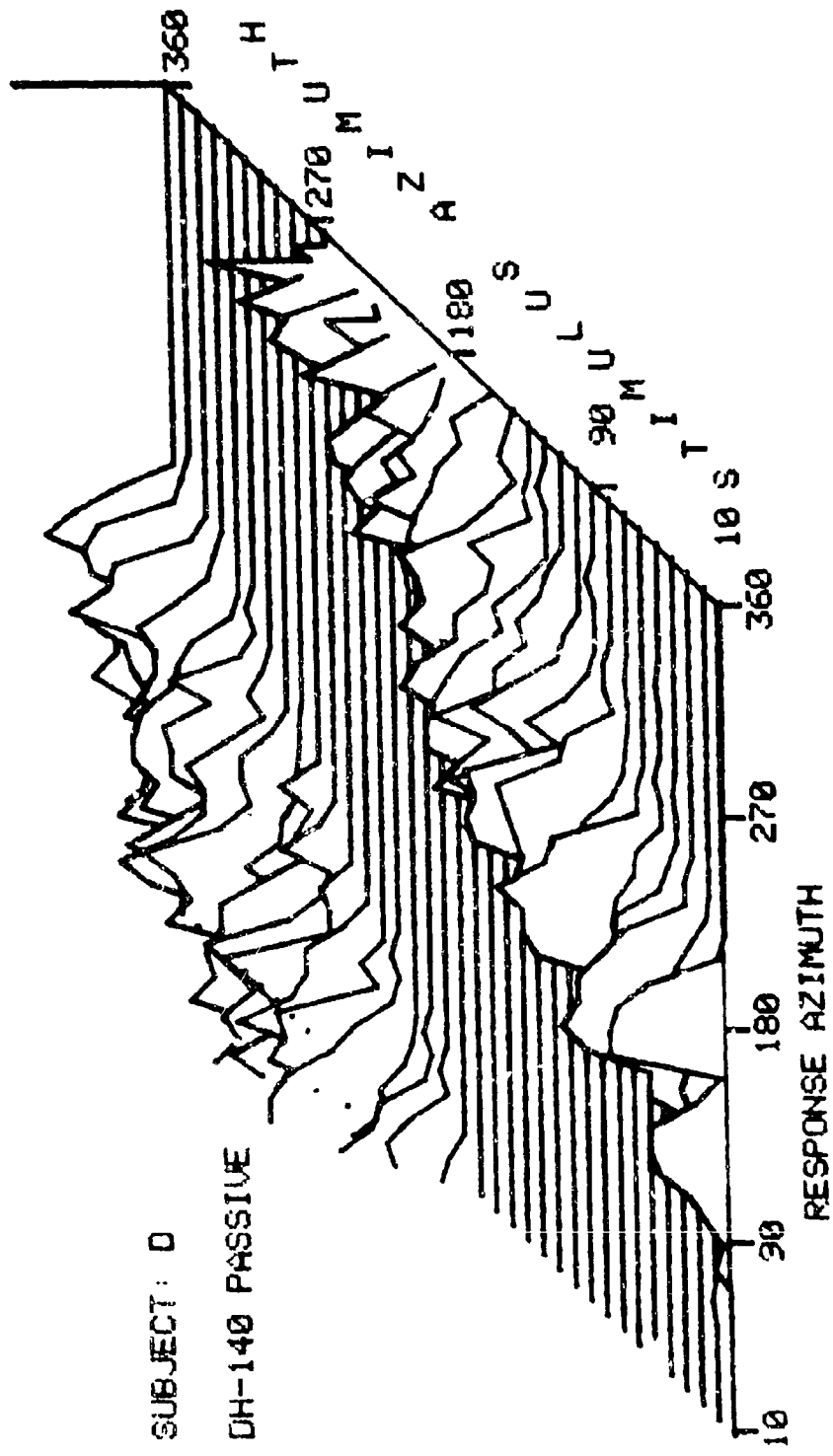
Fig. 12D

Fig. 12E

Fig. 12F

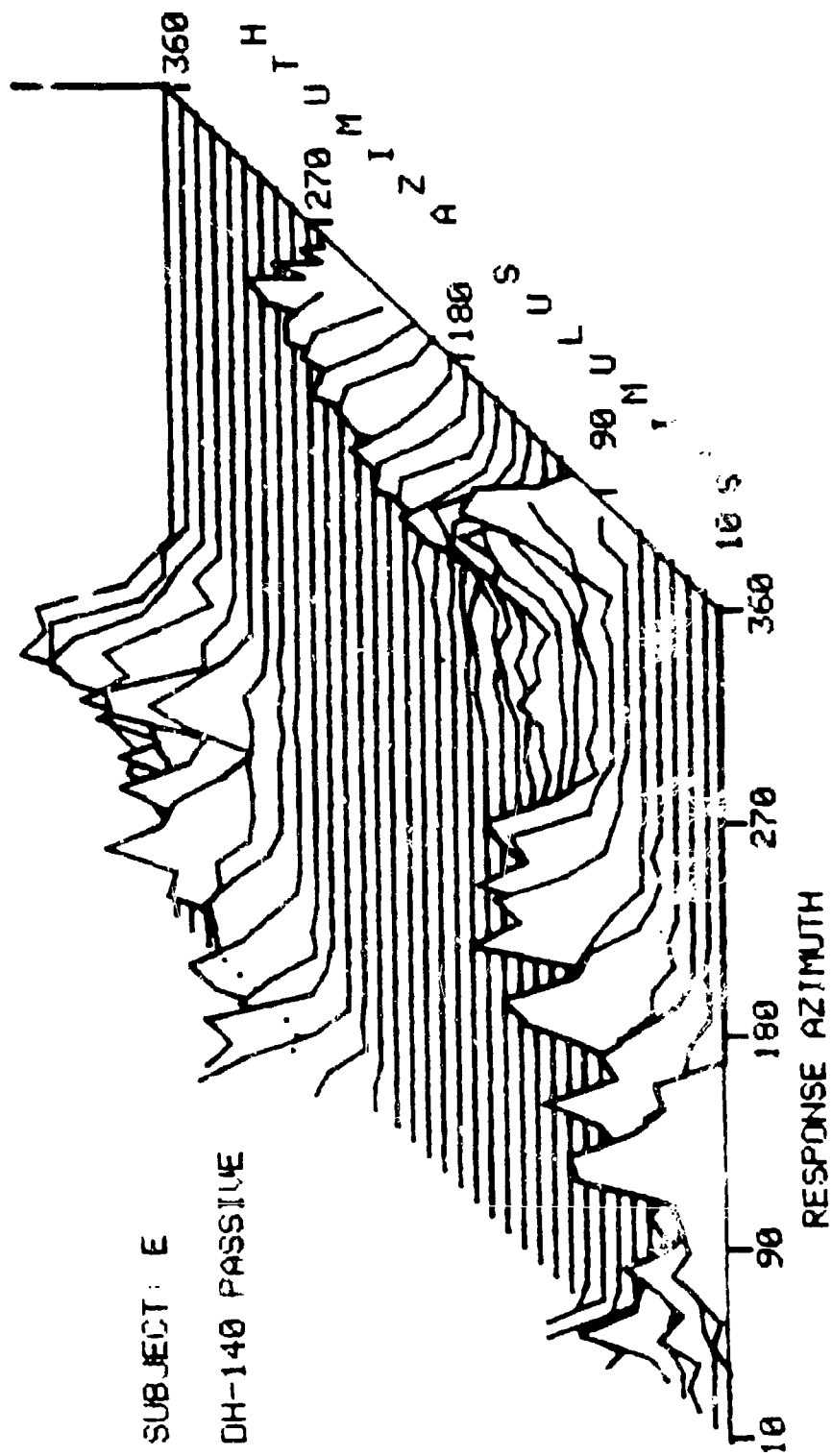
SUBJECT: D

UH-140 PASSIVE



SUBJECT: E

DH-140 PASSIVE





SUBJECT: F

DH-140 PASSIVE

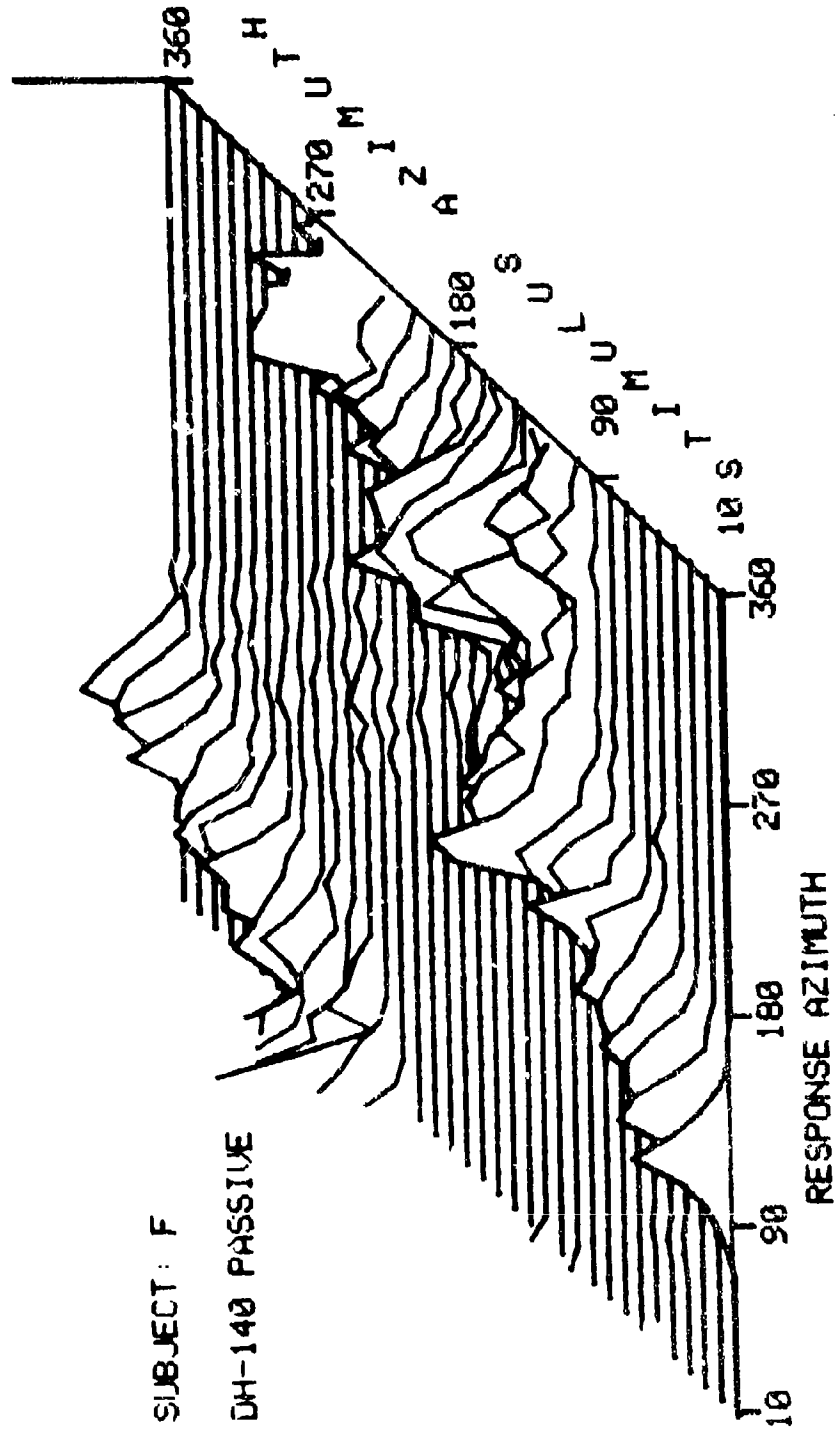


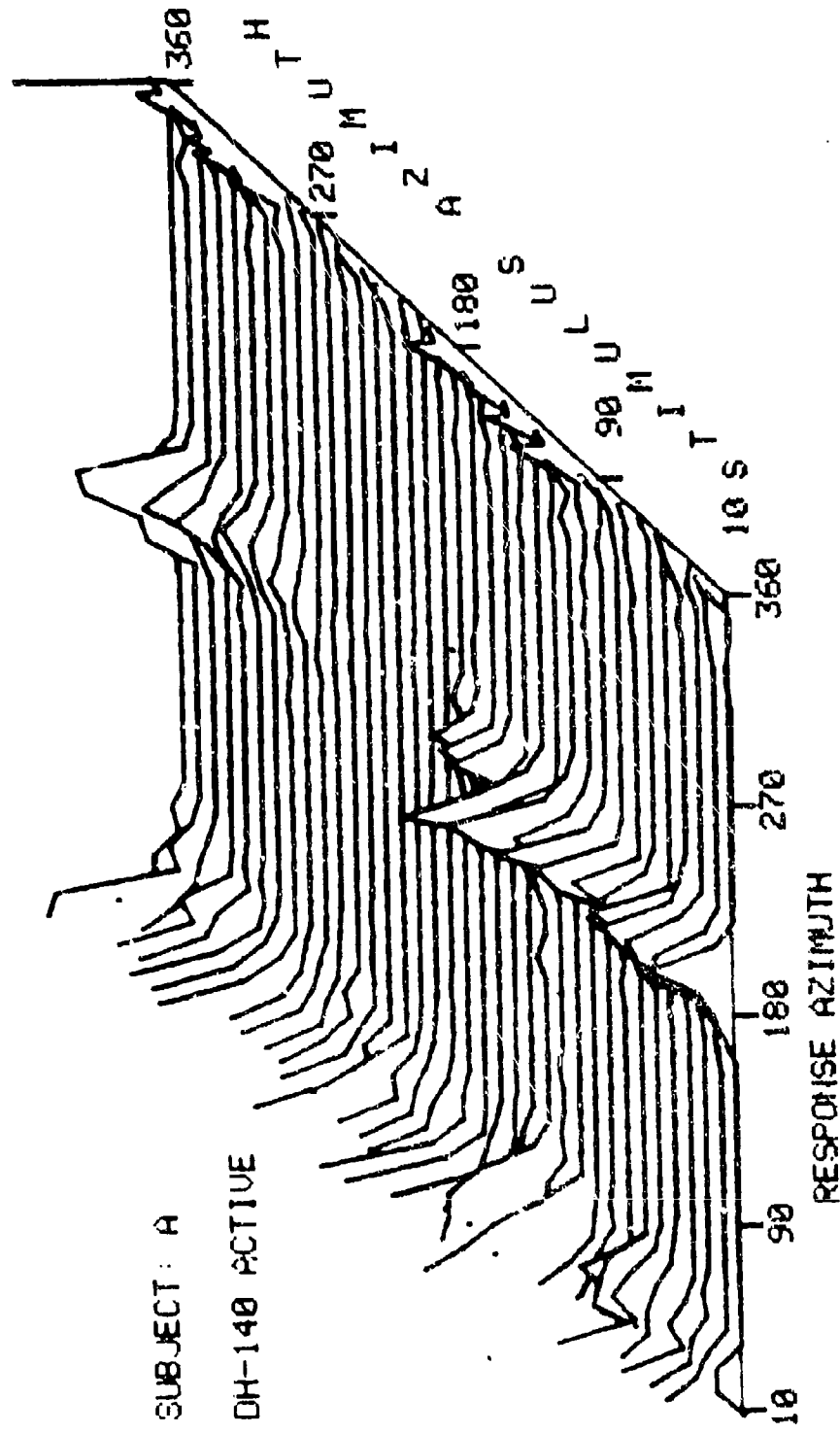
Fig. 13A

Fig. 13B

Fig. 13C

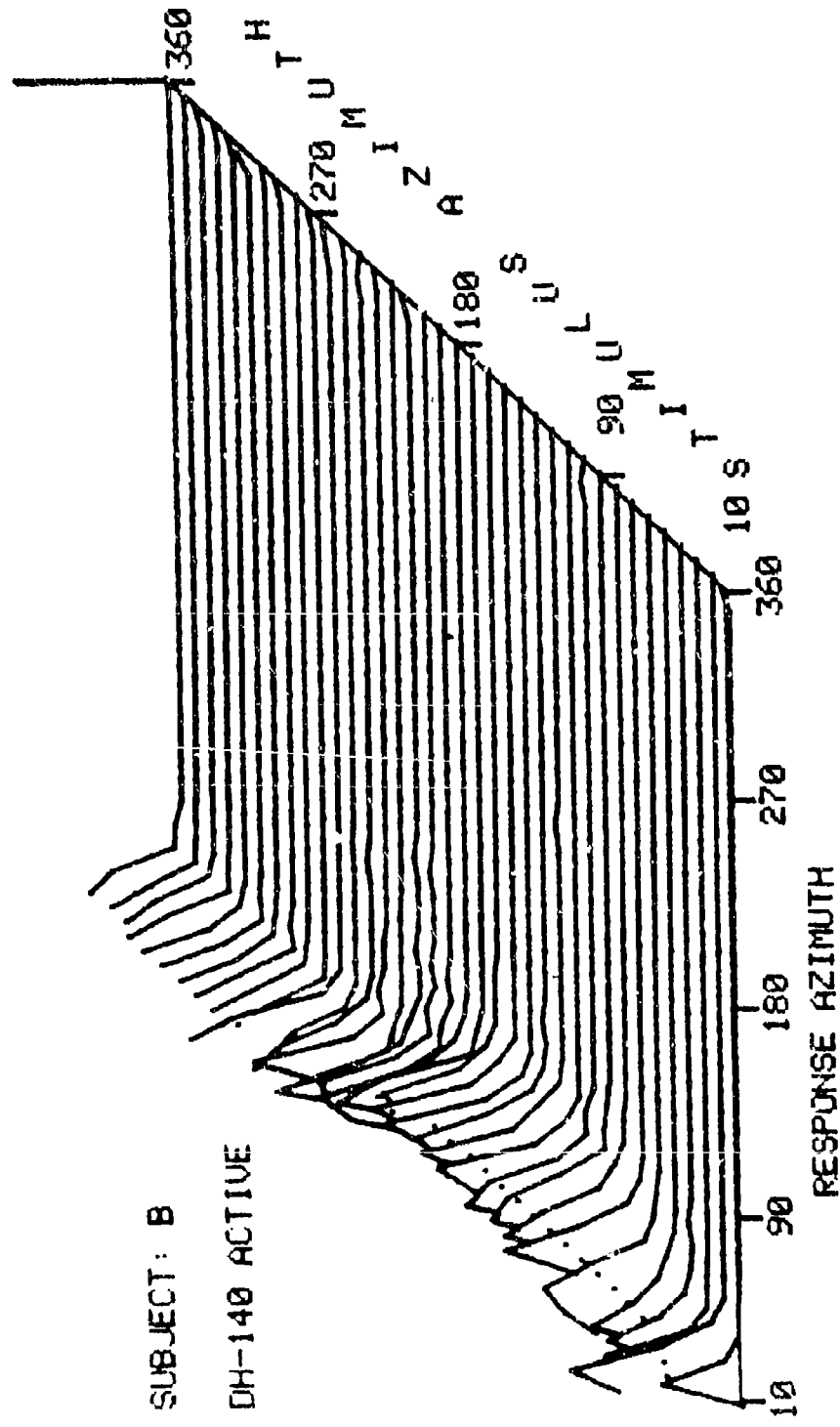
FIGURE 12. Response frequency surfaces for the six subjects using the OH-140 helmet in active mode.

SUBJECT: A  
DH-140 ACTIVE



SUBJECT: B

DH-140 ACTIVE



SUBJECT: C

OH-140 ACTIVE

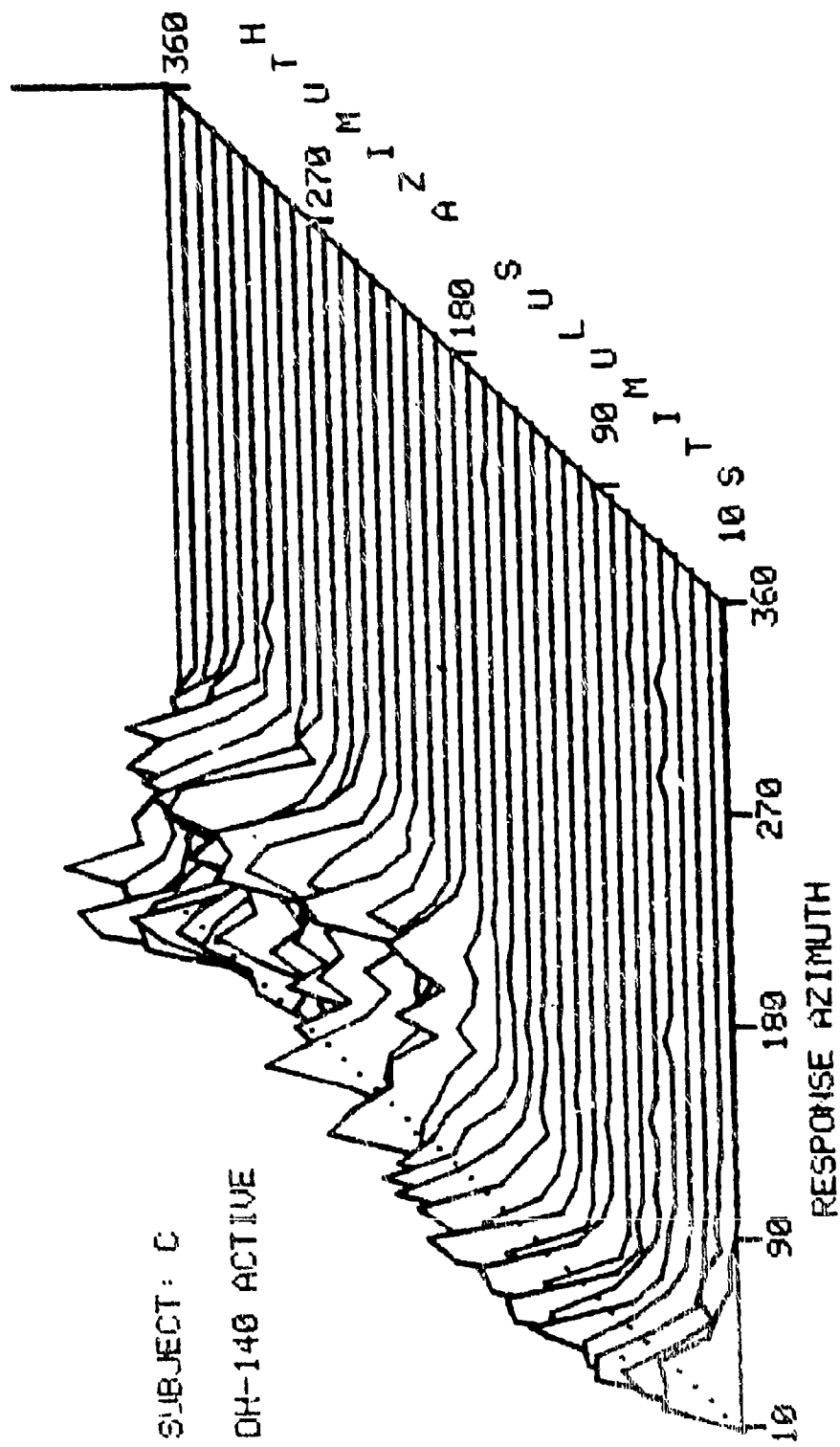
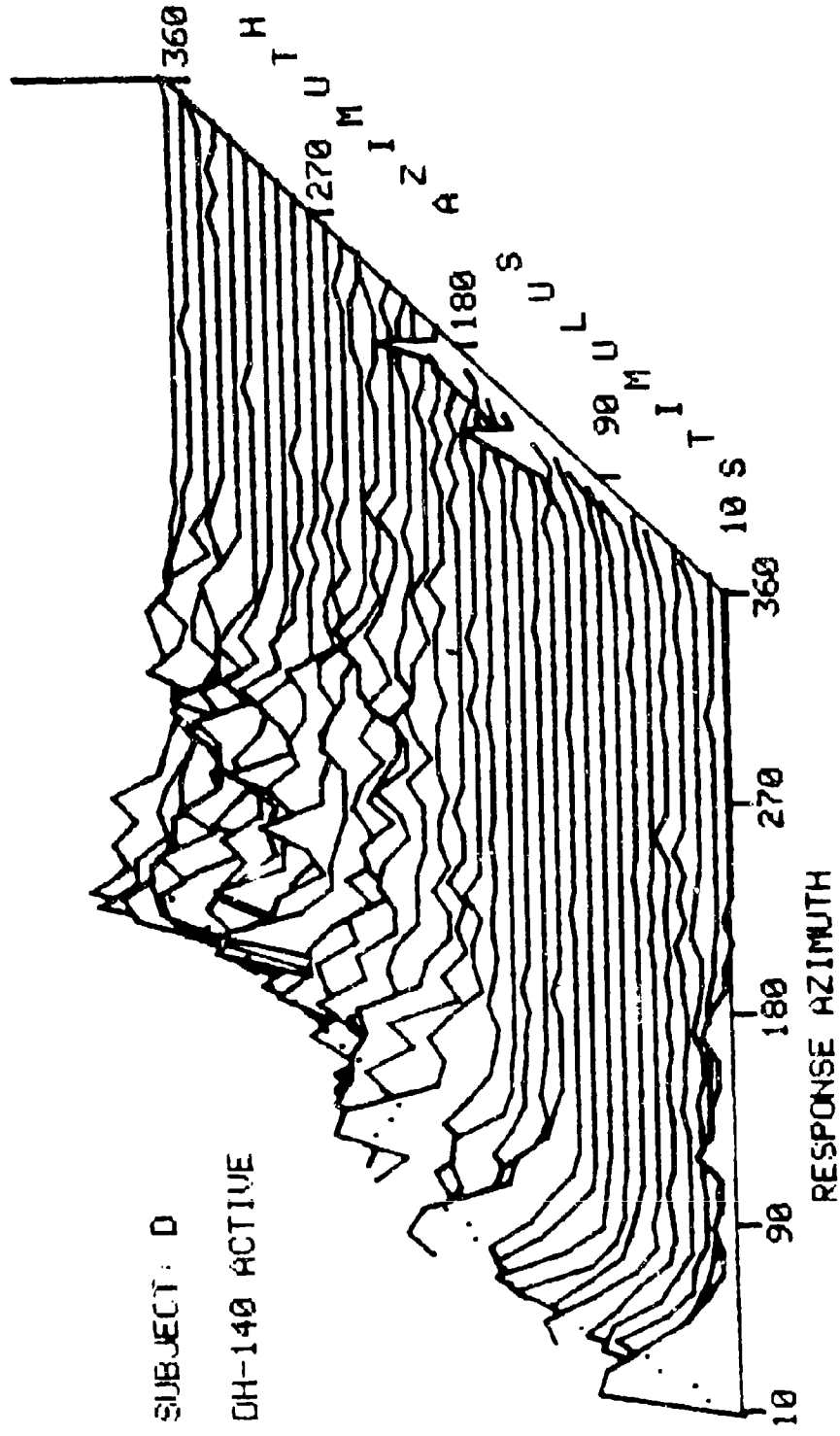


Fig. 13D

Fig. 13E

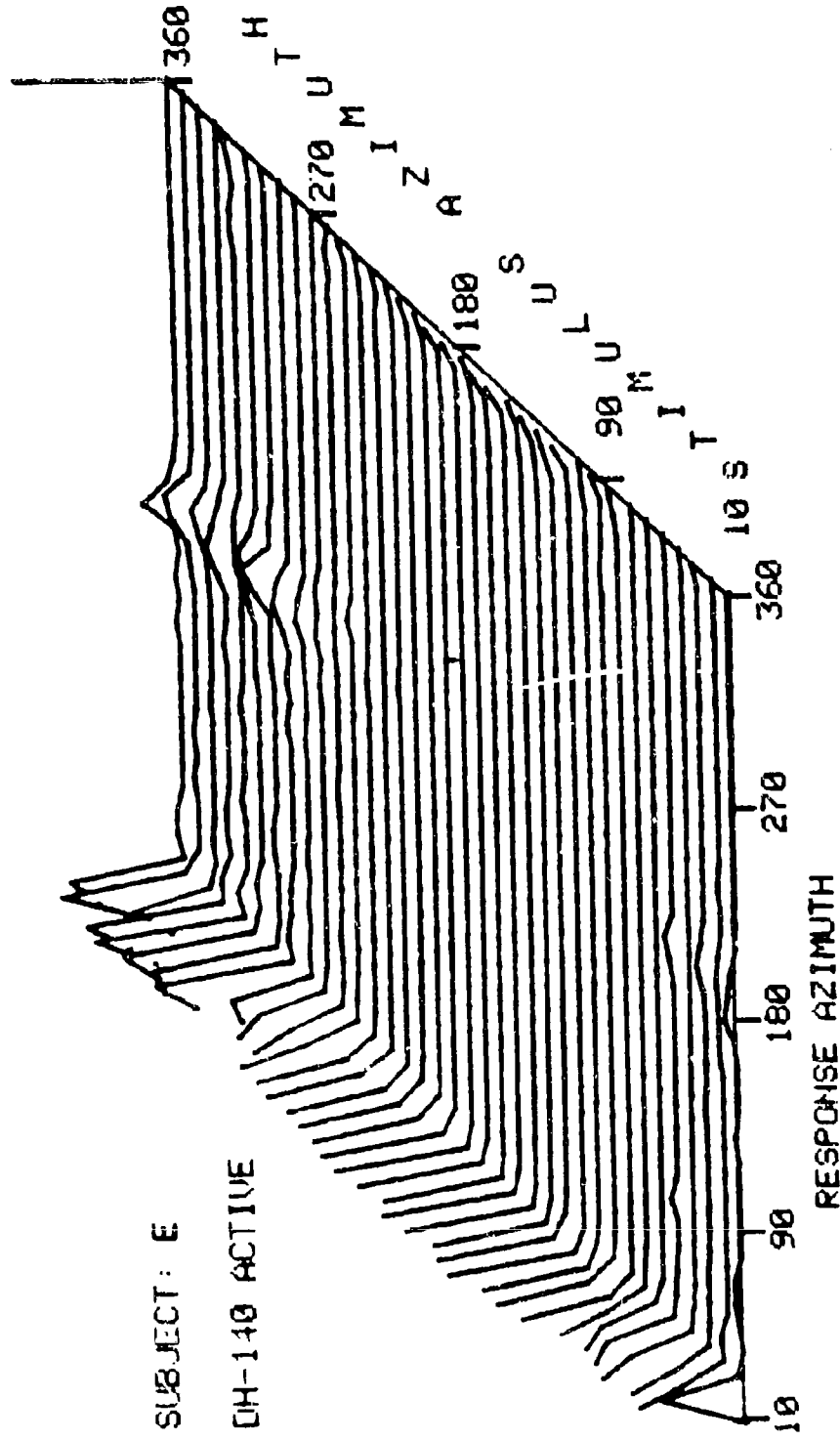
Fig. 13F

SUBJECT: D  
DH-140 ACTIVE



SUBJECT: E

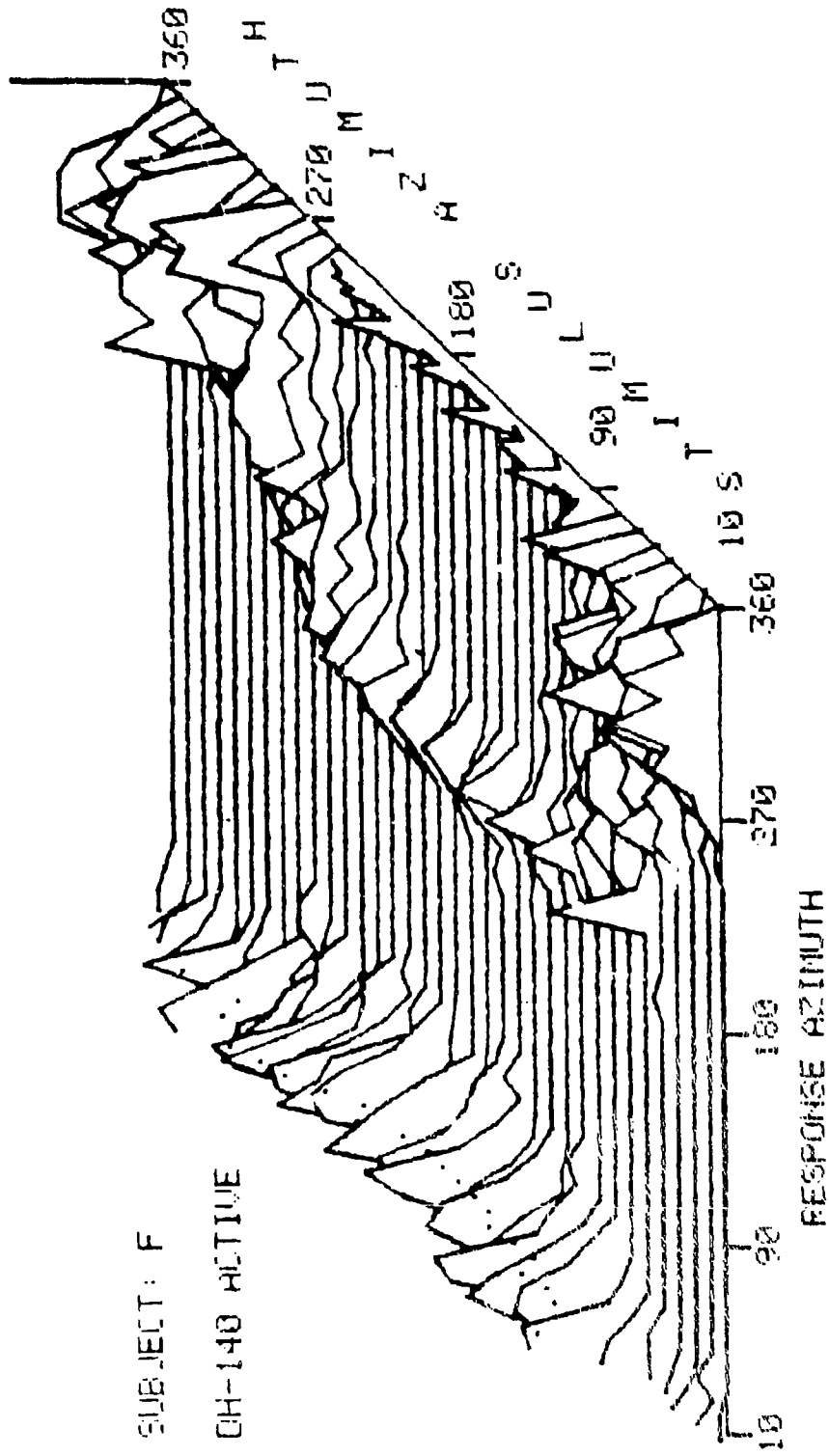
DH-140 ACTIVE





SUBJECT: F

CH-140 ACTIVE



## DISCUSSION

To illustrate the response patterns seen in Figures 9 through 13, several models of responding are presented in Figure 14. These models are invariant within levels of stimulus azimuth. Model 1 illustrates perfect following of apparent azimuth with stimulus azimuth. The characteristic ridge along the main diagonal in this model is most clearly evident in Figure 9, subjects C and D. This primary model of perfect responding has been altered by systematic rotations of the data matrix to produce the other models in Figure 14.

Model 2 is a  $180^\circ$  rotation of Model 1. This pattern, dominated by two diagonal ridges, may be seen clearly in Figure 10, subjects A, B, C and D, and in Figure 12, subjects B, C and D. This  $180^\circ$  rotation infers a perceptual situation different from that described in most studies involved with front-back localization reversals. At least for these subjects, while wearing helmets with passive circumaural hearing protectors, simultaneous reversals of front with back and left with right have occurred. Rather than an increase in confusion of loci, a systematic displacement of apparent azimuth appears to result from the use of this type of headgear. Other subjects (E and F in Figure 10 and subjects A, E and F in Figure 12) under the same conditions appear to have been less disturbed. Three possible explanations for their behavior arise: (1) these subjects may have consistently achieved a poor acoustic seal in these conditions, compromising attenuation and minimizing disturbances of cues to localization, (2) these subjects learned to associate displaced cues to localization with the correct physical azimuths, and (3) these subjects relied on cues not affected by the helmets.

The first alternative may be considered improbable because all subjects were given specific training and motivation in fitting the helmets properly and consistently, and they appear to have been strongly influenced by the helmets under other conditions. If the second alternative were true, it would be expected that the response patterns would reflect the learning process as systematic confusions of loci. The response patterns should resemble a combination of Model 1 and Model 2. It should also be noted that no response feedback was given to observers during the sessions. Verification of the efficacy of response strategies for recoding localization cues could only occur between sessions. The third alternative appears more likely if one considers that interaural time delay and interaural amplitude difference may be less affected by circumaural hearing protectors than the other cues for localization. It may be that interaural difference cues are emphasized by some observers when other cues are degraded.

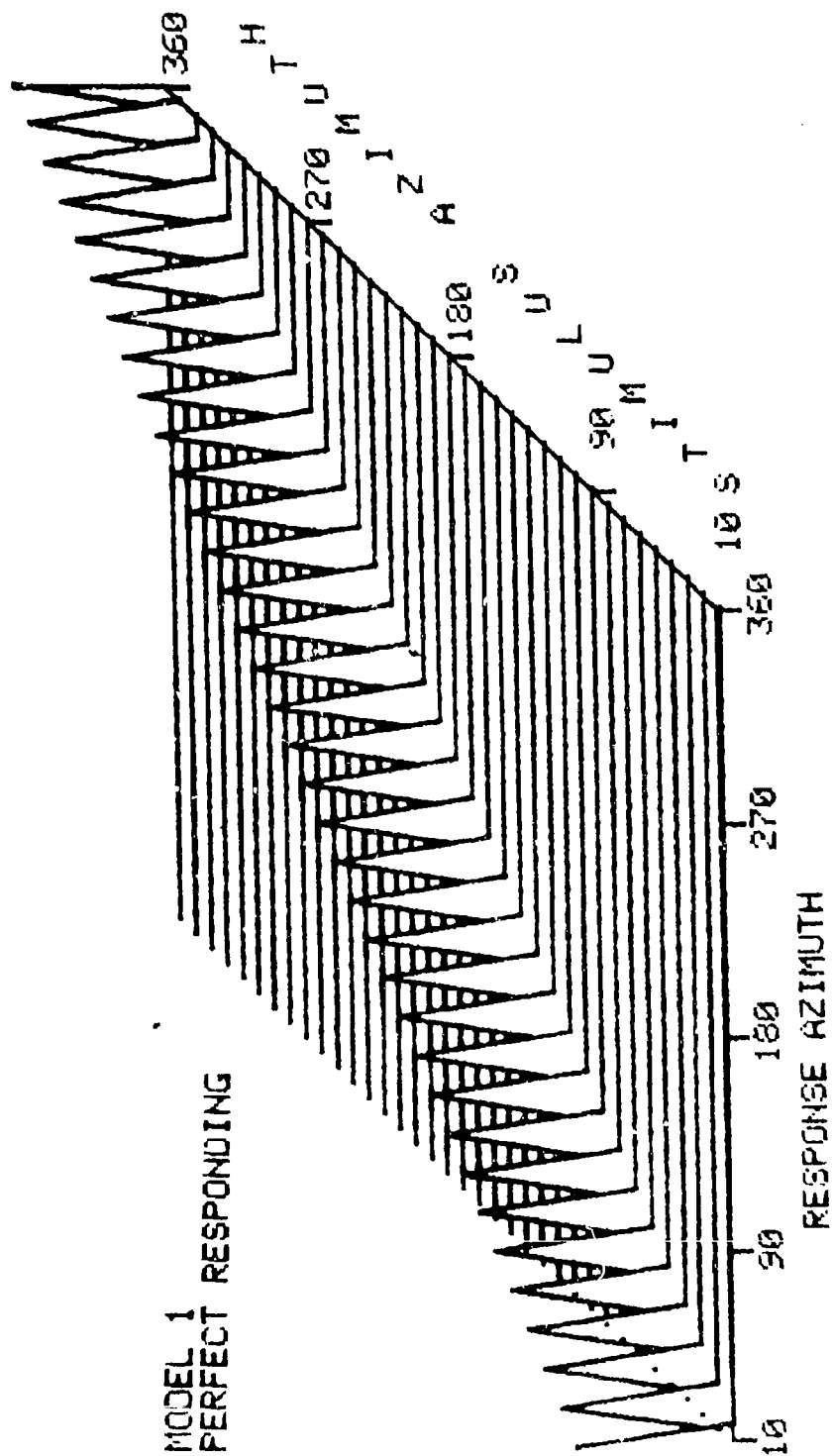
Models 3 and 4 in Figure 14 are complementary rotations of Model 1 by  $90^\circ$ . These do not represent any expected results from the experimental conditions but illustrate extreme response biases. Such biases might be perceptual or motor in origin. For example, in turning a response dial, a subject may be more likely to overshoot the intended position in one direction. Individuals also have postural habits, particularly with regard

Model 1

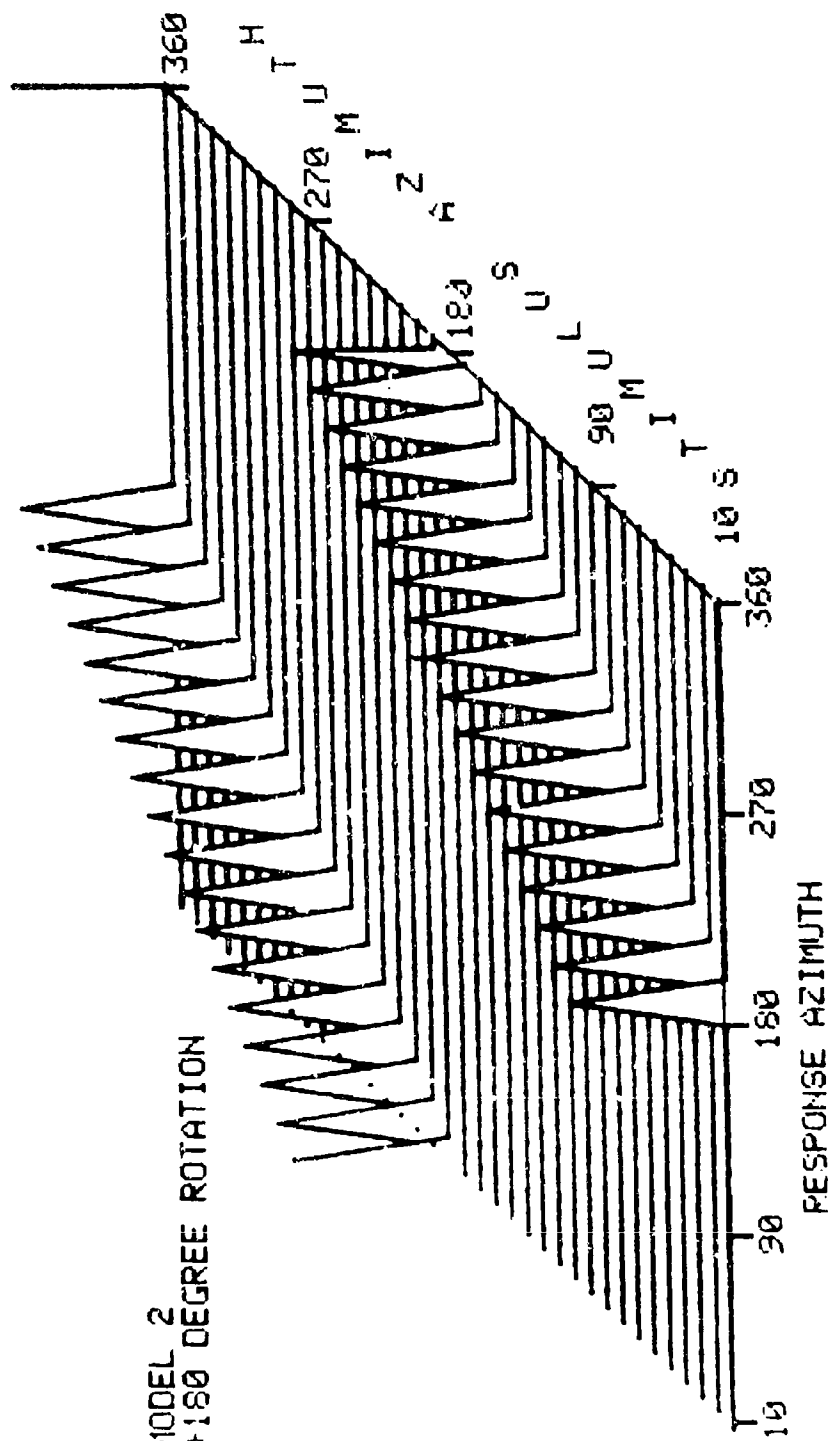
Model 2

FIGURE 14. Several models of possible response patterns constructed by permuting Model 1, a representation of perfect following of stimulus azimuth. All models are invariant within levels of stimulus azimuth. Response frequencies (vertical axis) are all equal and arbitrary. Model 2 is a  $180^\circ$  rotation of response azimuth with respect to stimulus azimuth. Models 3 and 4 are complementary  $90^\circ$  rotations illustrating extreme response biases as displacement of response azimuth. Models 5 and 6 are complementary foldings of response azimuth at the interaural axis. Model 7 results from reversal of Model 6 about the midline. Models 8 and 9 are complementary reversals about the interaural axis and midline. Model 10 is a folding of response azimuth at midline, analogous to Figures 5 and 6.

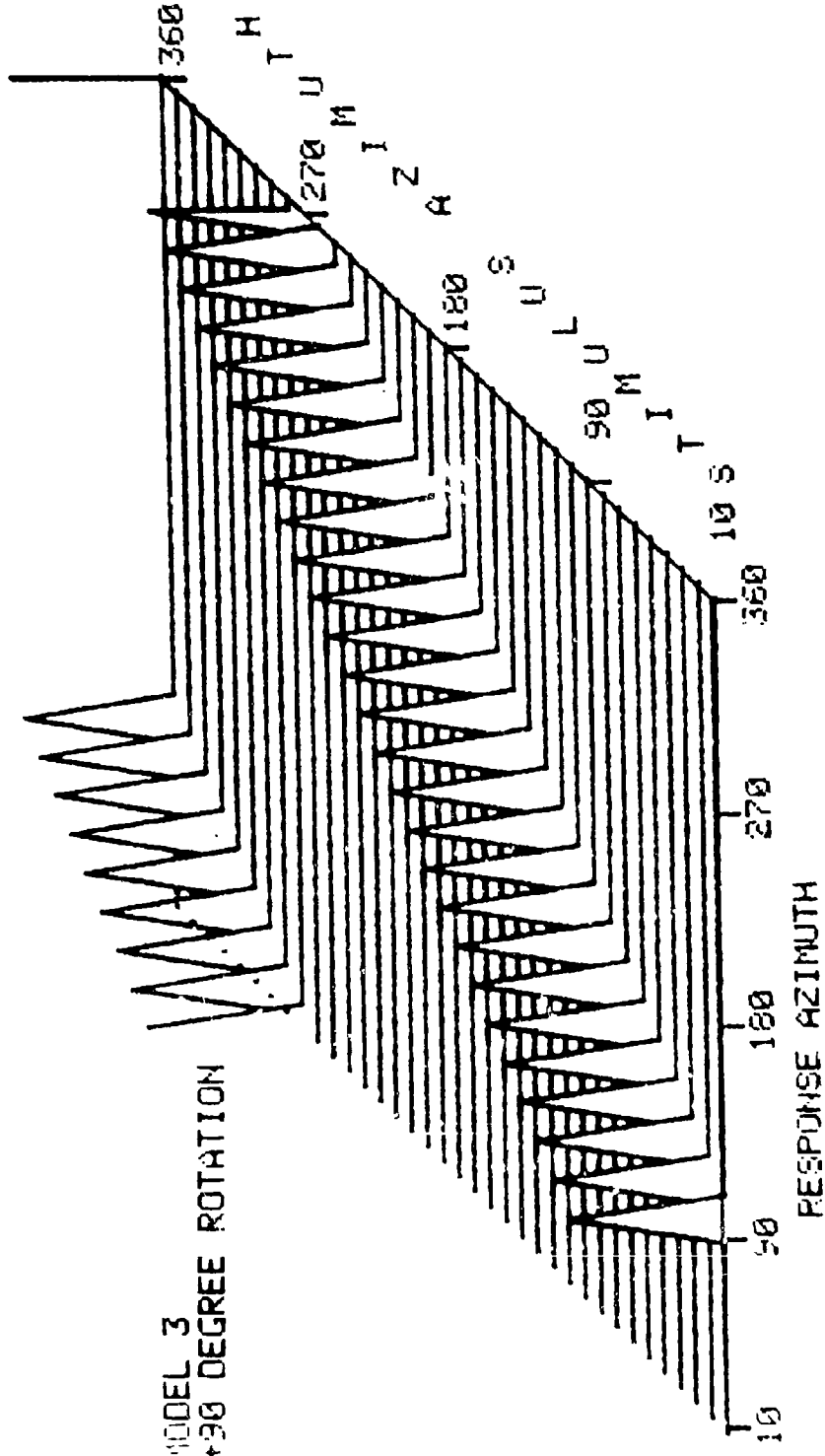
MODEL 1  
PERFECT RESPONDING



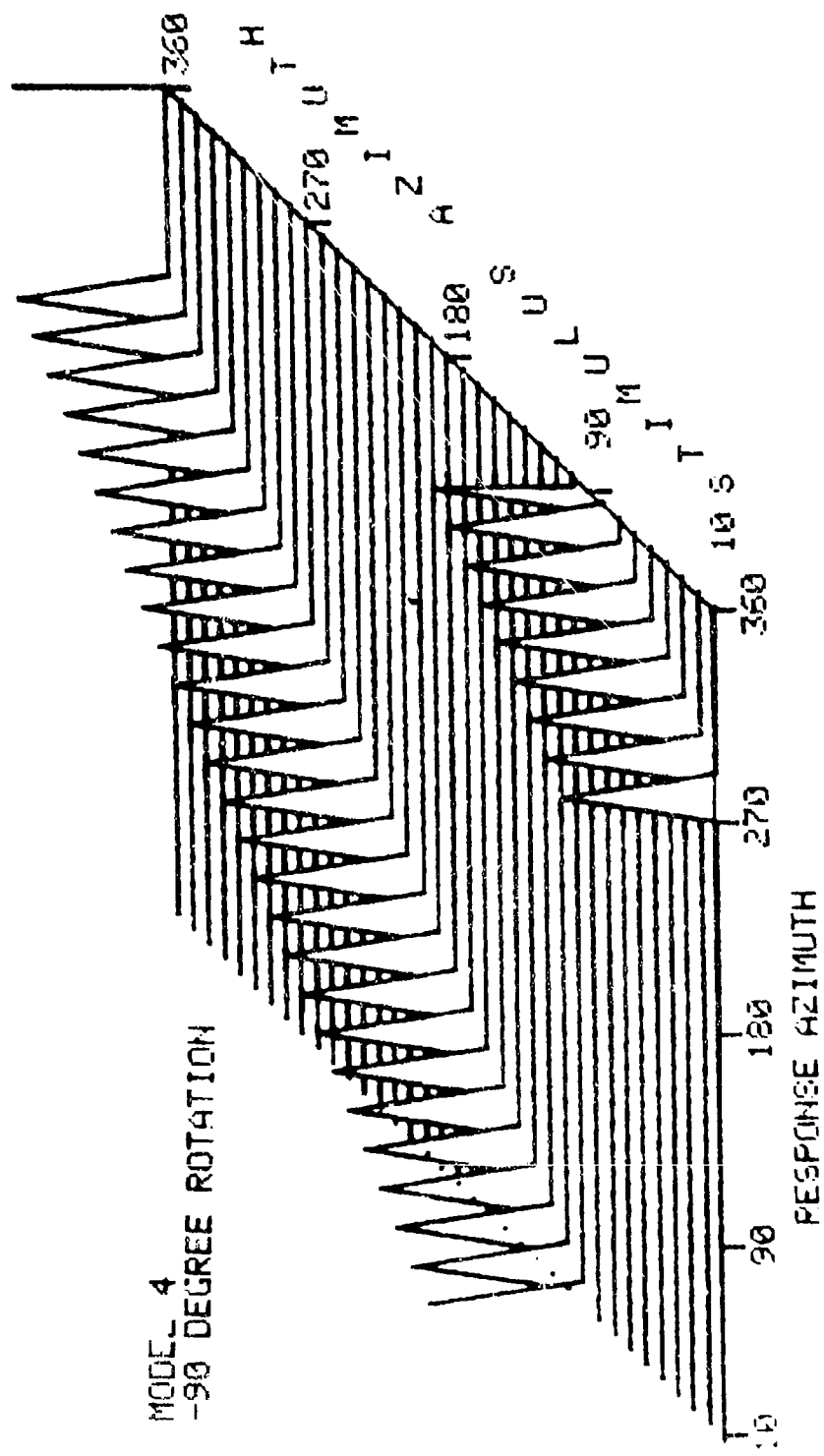
MODEL 2  
+180 DEGREE ROTATION



MODEL 3  
+90 DEGREE ROTATION



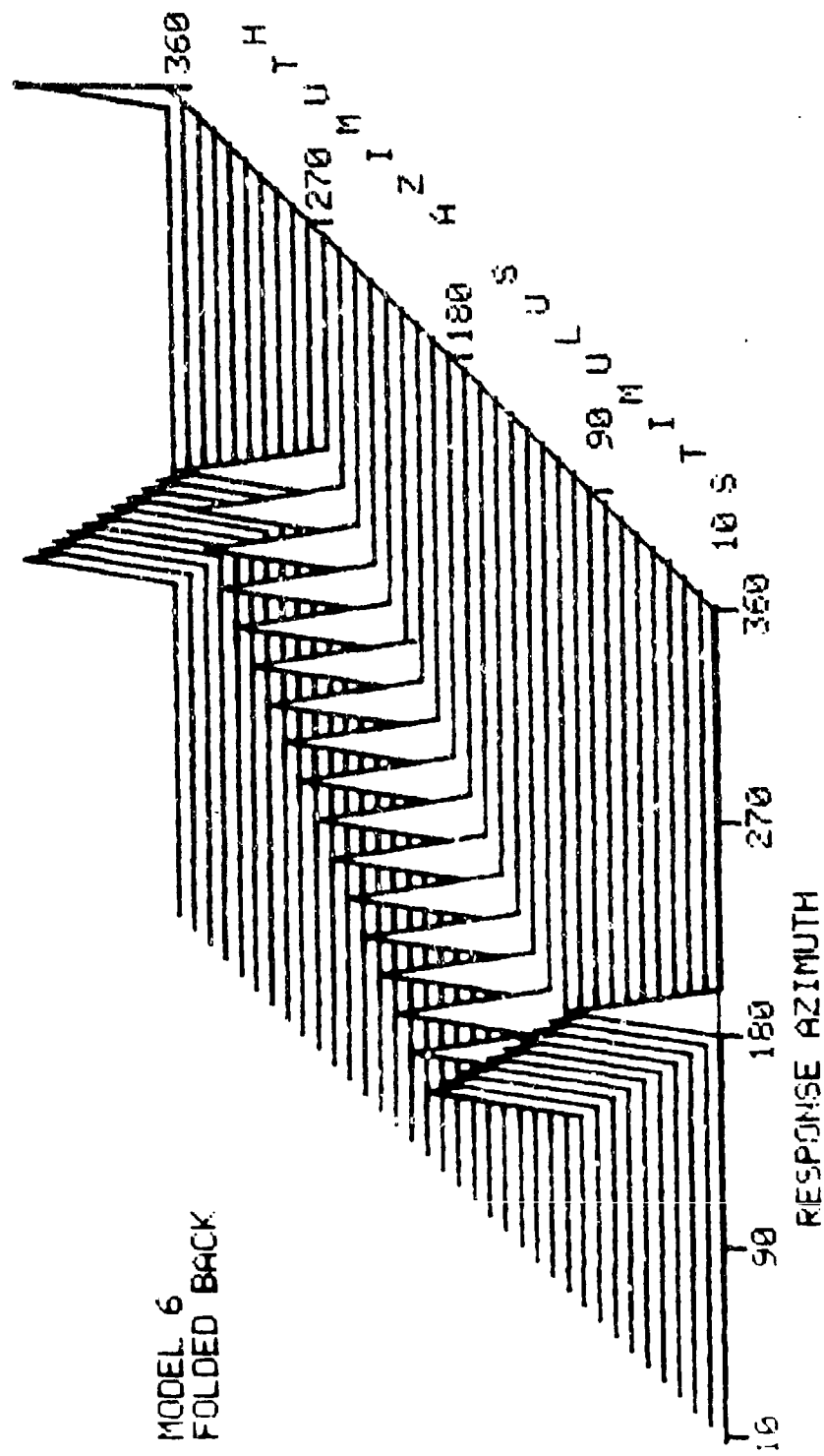
892



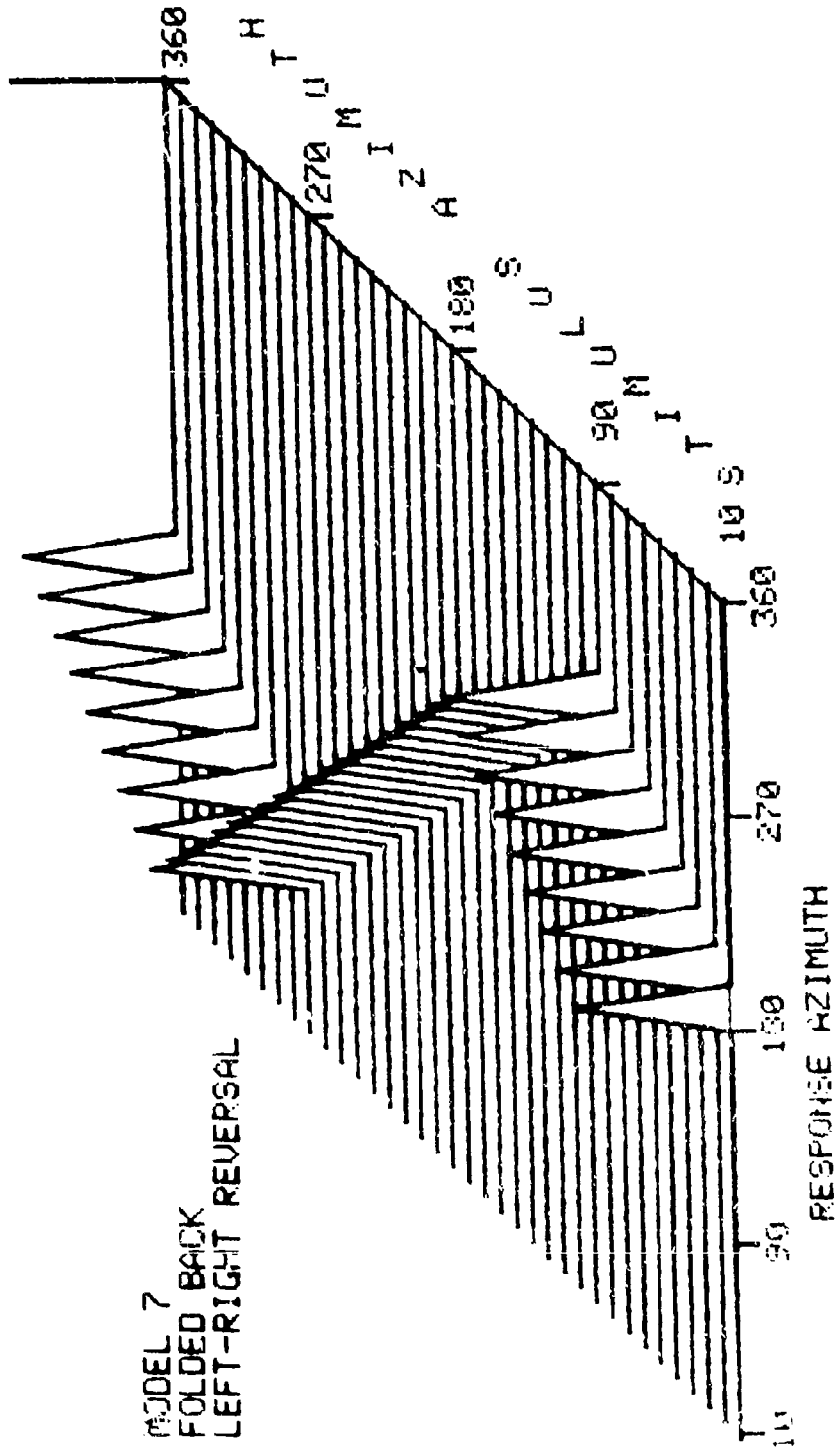




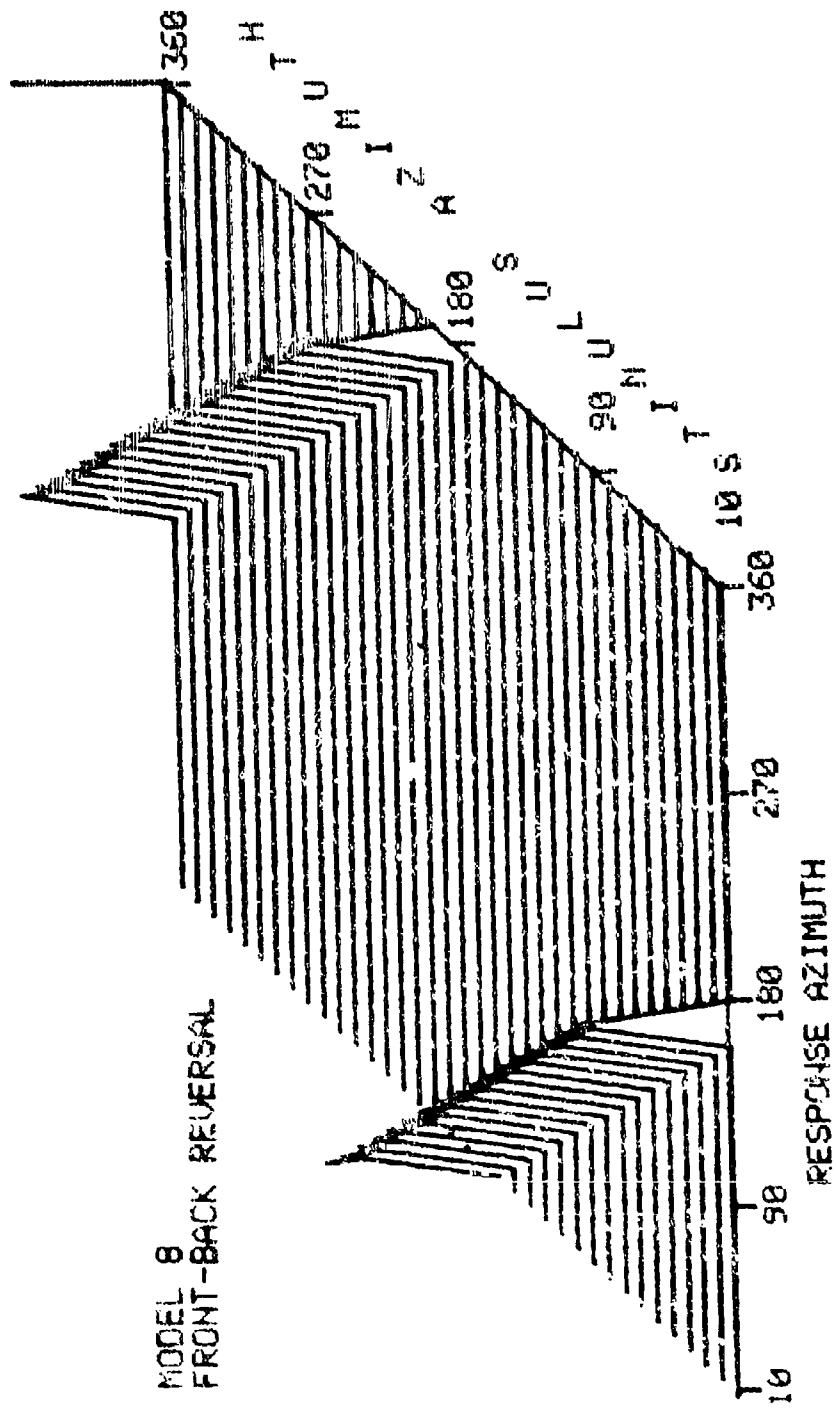
MODEL 6  
FOLDED BACK



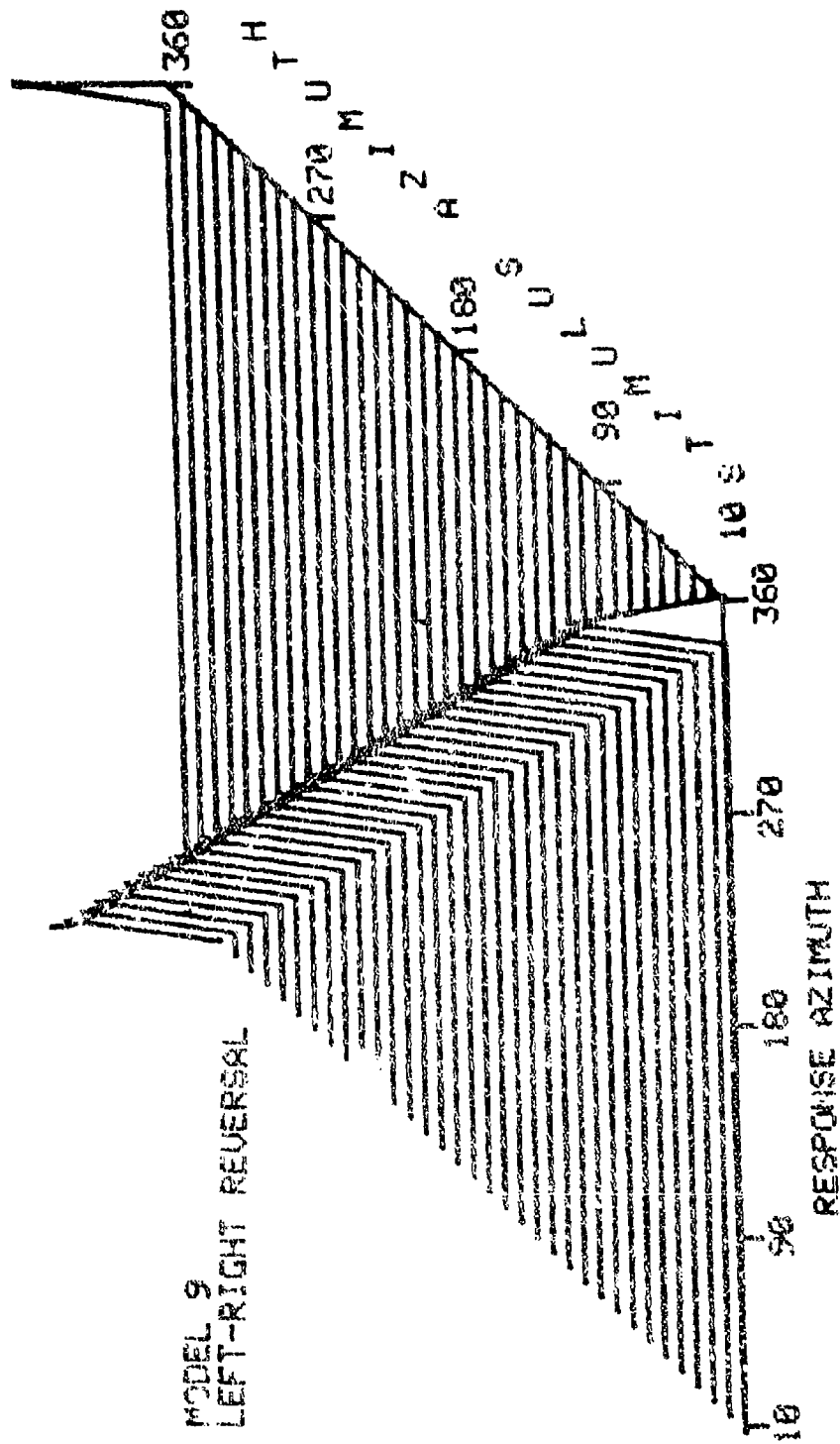
MODEL 7  
 FOLDED BACK  
 LEFT-RIGHT REVERSAL



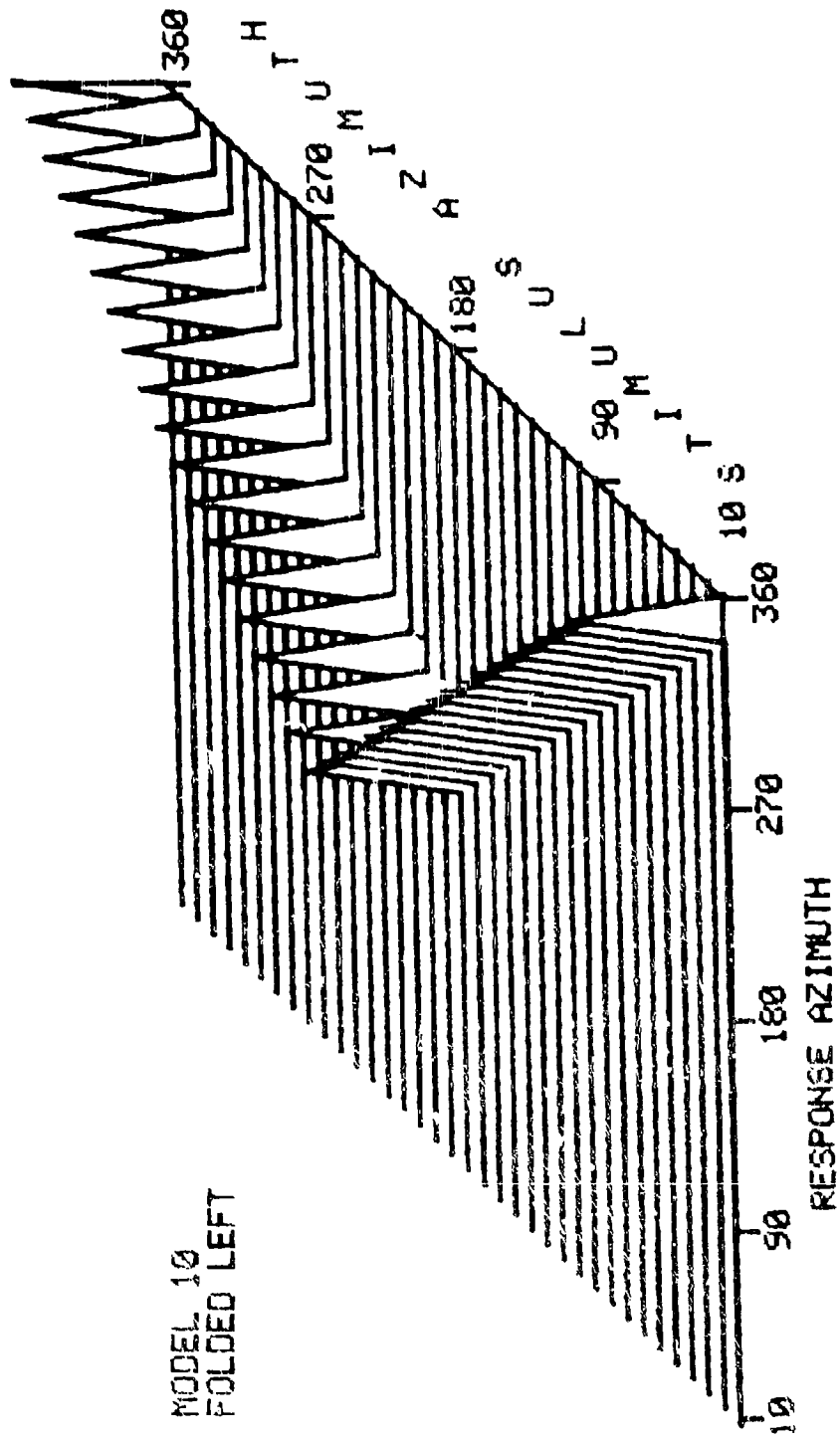
# MODEL 8 FRONT-BACK REVERSAL



MODEL 9  
LEFT-RIGHT REVERSAL



MODEL 10  
FOLDED LEFT



to head position, and it is possible that overriding these habits (as with the visual fixation target) could produce relative shifts in perceptual space. Response biases of lesser angular disparity than shown in Models 3 and 4 can be seen in Figure 9, subjects A, B, E and F. Models 3 and 4 depict complete displacement of apparent azimuth. The experimental data show biases in patterns of confusion expressed as lower secondary ridges.

Models 5 and 6 are more complex perturbations of Model 1. In Model 5 the data in the second quadrant were translated to analogous positions (with respect to midline) in the first quadrant and data in the third quadrant similarly translated into the fourth. This pattern may be described as a folding of auditory space to the front. Model 6, the complement of Model 5, is a folding of auditory space to the rear. Both of these models constitute a halving of the number of perceptual loci in the azimuthal plane. Although subjects reported consistent front images when the diotic (DH-140) active protector was used, the response patterns in Figure 13 do not resemble Model 5. The number of perceptual locations available to the observers in this condition was effectively reduced to one or two. The pattern of Model 5 is barely discernable in Figure 10, subject E, and may also be present in the data for subject F. Model 6 resembles the serpentine pattern seen with the dichotic active protector (Figure 11). However, closer examination reveals that the direction of bending of the central ridge produced by subjects A, B and F is opposite to that of Model 6. Their response patterns may be more closely approximated by Model 7. In this case, a left-right reversal has been introduced by translating quadrant I to quadrant III and quadrant IV to quadrant II.

Model 8 is a representation of complete front-back reversal with preservation of laterality. Quadrants I and II have been exchanged and quadrants III and IV have been exchanged. An increase in the rate of front-back confusion would be seen in the response patterns as a combination of Model 1 with Model 8. This pattern of confusion is not apparent in the present data.

Models 9 and 10 were constructed for examination of left-right localization errors. In Model 9, complete left-right reversal is illustrated by exchanging quadrant I with IV and quadrant II with III. This pattern does not appear in any of the data produced in this experiment. Simple reversal or confusion of left with right is not evident. Model 10, which is analogous to Models 5 and 6, is the result of translation of quadrant I into quadrant IV and translation of quadrant II into quadrant III. As with Models 5 and 6, this is a halving of the number of available perceptual loci in azimuth. Neither this left-fold nor a complementary right-fold pattern are evident in the present data.

It appears, from the present data, that the introduction of passive circumaural hearing protectors disrupts auditory localization more extensively than might have been predicted, although some subjects appear to be minimally affected by them. It is hypothesized that some individuals may be predisposed to (or may even select) localization cues which are comparatively

robust to passive protectors (most probably non-pinna cues). It would be beneficial to investigate interaural difference cues separately from the others. Subjects who are disturbed by passive protectors seem to be operating with rearranged localization cues. The dominant pattern of errors indicates that the range of perceptual loci available is preserved but systematically displaced. The obvious implication is that the cues might be eventually recoded to compensate for the displacement. Studies of such compensation indicate that lengthy experience is required for even incomplete compensation for displaced spatial cues (Elfner and Perrott, 1966; Navarro, 1972; Russell, 1977).

The outcome for the active hearing protectors studied here is less encouraging. The patterns of errors produced when these devices were used indicate an essential elimination of auditory localization facility. In the case of the diotic system, severe disruption of localization was expected as a result of correlation of information at the two ears. The loss of localization is more extensive than expected. The placement of a single microphone on the left side results in obvious differences in loudness between left and right sound sources. Even when aware of this enhancement of head shadow effect, subjects were unable to assign perceptual loci to the left or right.

With a dichotic signal available, the pattern of responding was different but little more successful than with the diotic device. Interaural time delay and interaural amplitude difference should be intact cues in this condition, but were apparently overwhelmed by other aspects of the auditory input. Assuming that the electroacoustic characteristics of the active devices used in this study are similar to those of an earlier prototype measured by Patterson et al (1978) the causes for the loss of localization facility are evident. This prototype device produced a frequency response curve characterized by a 20 dB per octave roll off above 2.5 kHz, a 30 dB per octave roll off below 2.5 kHz, and severe resonant peaks at 2 kHz, 3 kHz and 4 kHz. The device is essentially a distorted narrow band filter centered at 2.5 kHz. Most of the spectral range, over which auditory localization cues operate, is severely attenuated and any residual information is disturbed by harmonic distortion. Even the relatively weak shoulder bounce cue, with a functional range coincident with the center frequency of the amplifier frequency response curve is confounded by distortion.

Much of the lost information might be recovered simply by using amplifier circuits with reasonably broad and smooth passbands. Auditory localization ability might then be further improved by addition of acoustic analogs for pinna response characteristics. This would be futile unless an electroacoustic channel capable of carrying the added information is first provided.

The study reported here is a very narrow assessment of auditory localization ability. It does not address major dimensions such as discrimination of loci in azimuth, identification and discrimination of elevation, perception of distance and spatial extent, or any dynamic aspects

of localization. Furthermore, the use of multiple transducers should be viewed as a less than optimal method for investigating static localization because of a tendency to degrade the anechoic property of the sound field, and because of the opportunity for response bias due to speaker signature differences.



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Shaw, E. A. G. 1974. Physical models of the external ear. *Proceedings of the 8th International Congress on Acoustics*. Volume 1:206.

Tobias, J. V. (Ed). 1972. *Foundations of modern auditory theory*. New York: Academic Press.

## APPENDIX A

### List of Equipment Manufacturers

Bruel and Kjaer Instruments, Inc.  
185 Forest Street  
Marlborough, MA 01752

Digital Equipment Corporation  
Maynard, MA 01754

Gen Rad  
300 Baker Avenue  
Concord, MA 01742

McIntosh Laboratory, Inc  
East Side Station, P.O. Box 96  
Binghamton, NY 13904

Time/Data  
Subsidiary of Gen Rad  
2855 Bowers Avenue  
Santa Clara, CA 95051

Coulbourn Instruments  
Box 2551  
Lehigh Valley, PA 18001

Elgenco Inc.  
Santa Monica, CA 90406

Industrial Acoustics Company, Inc.  
1160 Commerce Avenue  
Bronx, NY 10462

Oaktron Industries, Inc.  
Monroe, WI

Gentex Corporation  
P.O. Box 315  
Carbondale, PA 18407